Harry Ricardo – A Passion for Efficiency

David Morrison

Harry Ricardo, born in 1885, was a true pioneer of internal combustion engine research and development, designing and building his first practical engine from the age of 16. His early life, especially at Trinity College, Cambridge, coincided with some key embryonic developments in internal combustion engines, which had a strong influence on his research, especially the work of Bertram Hopkinson and Sir Dugald Clerk. He was passionate about energy efficiency in both his business and private life.

This paper covers Harry Ricardo's early work, experimenting with stratified charge concepts as early as 1903, leading to his work in the early decades of the twentieth century which generated internationally-renowned designs in both diesel and gasoline road vehicle combustion systems. Of these, perhaps the Comet indirect injection system for diesel engines was the most prolific and persisted in various forms well into the 1980s. A very important opportunity for the company was the early work with Shell to study the influence of fuel properties, using a Ricardo variable compression ratio engine.

During his time, he had none of the powerful simulation and visualisation tools we take for granted today. He had to use his vivid imagination by trying to visualise what the airflow and fuel mixing must be like inside a combustion chamber.

Significant engines up to 1950 included the Dolphin two-stroke, the Comet IDI diesel engine for the world's first production diesel car – the Citroen Rosalie, the Rolls-Royce diesel conversion for the Flying Spray land speed record car and many developments of spark-ignition combustion systems, including the Turbulent Head. He pioneered four-valve high-performance combustion systems in a Triumph motorcycle in 1921 and in the 1940s, designed the prototype Rolls-Royce Crecy engine, seen as the peak of aircraft piston engine development.

Sir Harry Ricardo died in 1974 at a time when interest in engine exhaust emissions was gaining pace. He would have found the present era technically fascinating with the renewed demand for energy conservation combined with clean combustion.

KEYWORDS:
Ricardo Company, early engines, combustion chambers, litigation, automotive engines, aero engines, rail engines.

Introduction

This paper will mainly focus on the early years of Harry Ricardo and his businesses, up to the 1950s. It is a historical review of some of the early technical achievements and engines which illustrate the breadth of his interests in internal combustion and with some anecdotes reveals the character of the man and what drove him in his passion for engine technology and efficiency. With such a vast history of technical achievements and milestones, already comprehensively covered in many excellent publications,[1] a paper such as this can only hope to touch on the character and spirit of this special pioneer. For more technical depth and background to the Ricardo enterprises, readers are encouraged to delve into the reference material.

Harry Ralph Ricardo was born on 26 January 1885 at the family home in 13 Bedford Square, London, the eldest of three children, and only son of Halsey Ralph Ricardo, a successful architect, and his wife Catherine Jane, daughter of Sir Alexander Meadows Rendel, a civil engineer. The family name and origins can be traced back to sixteenth-century Portugal, and subsequently to Dutch links before the Ricardo name became best known in England during the eighteenth and early nineteenth century through the political economist, David Ricardo (Harry's great-great-uncle).

Educated at Rugby and Trinity College Cambridge and brought up in a civil engineering background, for some reason, Harry Ricardo's interests were much more directed towards mechanical systems and in particular, engines. Maybe this was because as a young child, he must have been one of very few people in the country to actually see a car when his grandfather purchased one in 1898. It must have had a big impact on his developing and keen imagination. He attended many lectures by leaders of technology at that time and was especially influenced by Bertram Hopkinson & Sir Dugald Clerk. In fact a major pivotal point of his life must have been a meeting with Hopkinson at the start of his third term at Cambridge. Clearly Harry had made a strong impression on his tutors from his work on a motorcycle engine in the college workshops. He explained to Hopkinson that his real interest was in moving machinery rather than stationary structures and Hopkinson endorsed and encouraged this view. Hopkinson then outlined a motorcycle fuel consumption competition, which Harry eagerly took part in and ultimately won.

> That win, although in a very minor competition, stands out in my memory as my greatest triumph, for I had put my whole heart and all my thoughts into its achievement.

This was also a period when pioneers like Nikolaus Otto & Rudolf Diesel were into their mature years and the world was poised on the brink of a major personal transport revolution. Harry Ricardo was ready for this challenge, and

with his mind focused on technical invention he went on to create and develop many of the world's pioneering internal combustion engines.

In his business life, Harry Ricardo was always known as "HRR" and so will respectfully be referred to as such in this paper, which is punctuated chronologically with selected photographs of HRR. Figure 1 shows him as a teenager.

Figure 1. Harry Ricardo as a teenager.

The Origins of the Ricardo Company

In 1907, HRR joined his grandfather's civil engineering consulting firm, Rendel and Robertson. He was principally involved in the design of mechanical engineering equipment for use in civil engineering applications. However, his true interests were rooted in engines and he devoted much personal time to research into engine combustion in his home workshop in his garden at Walton-upon-Thames. Around this time, he had also designed a two-stroke engine, originally for use in a car (this is described later). His research resulted in a number of patents and with support, notably from Mr Campbell Swinton, he was able to set up his first company as "Engine Patents Ltd" on 10 August 1915. This was of course war time and an important new military development was underway in the form of

a "tank" – so called, to conceal the true nature of the vehicle, which at the time was top secret. Word was put about that these were tracked water carrying tanks to supply the troops in the desert and so the perhaps inappropriate name "tank" has stayed to this day.

The existing engines suffered from lack of performance but worse, produced copious amounts of visible smoke, which was not ideal on the battlefield, instantly revealing their positions to the enemy. HRR was asked to cooperate with Mirrlees, Bickerton and Day in the design of new engines for these tanks, which culminated in a successful and greatly improved engine. As a result of this work, the War Office paid the agreed royalties on 1400 engines, to the tune of £30000. Today, that would be equivalent to a little over £1million. This resource opened up new possibilities and so substantially larger premises were planned at a new site. HRR had associations with the small fishing town of Shoreham-by-sea in Sussex both as a child on holidays to the seaside and then later when involved with the Dolphin car project, which happened to be based in Shoreham. He clearly felt comfortable in the quiet rural area and in August 1918 negotiated the purchase of 3 acres of land on the outskirts of the town, for £225. His architect father, Halsey Ricardo, was commissioned (for £1200) to design the first buildings on this green-field site, in the style of traditional Sussex farm houses, with truncated red-tiled roofs (these buildings still exist).

HRR spent some £15000 in the construction of these test facilities including transporting his equipment from Walton-upon-Thames and so "Bridge Works" became first established in 1919. Further test shops were added in the 1920s together with more land. There were also some company name changes, but from 1927 the name "Ricardo & Company Engineers (1927) Ltd" endured right up to 1978. During the 1940s the site was regarded as vulnerable from air attacks and so the entire company evacuated to Oxford. On its return in 1945, more space was required and in the following year the adjacent 83-acre Pad Farm was bought for £8000.

Over the subsequent decades, further extensive development occurred and today with comprehensive design and test facilities plus 600 staff, Ricardo Shoreham Technical Centre, officially named "The Sir Harry Ricardo Innovation & Sustainable Transport Centre" by the Duke of York in 2008, is the headquarters for Ricardo global operations and the largest of three technical centres in the UK.

First Internal Combustion Project

As an undergraduate at Cambridge University, HRR built a small steam engine for his bicycle, which must have generated considerable excitement and entertainment. However, he was more interested in *internal* combustion and at the age of 16 commenced the design of a spark-ignited single cylinder engine (Figure 2) to be used for pumping water at his parents' house in Graffham, West Sussex.

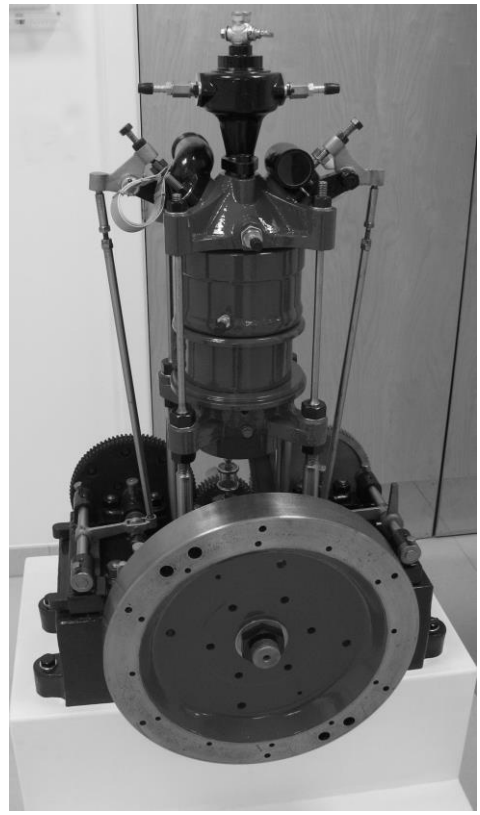

Figure 2. Harry Ricardo's first internal combustion engine.

This was his first attempt at designing and constructing an internal combustion engine and was built in stages between 1901 and 1903 over the school holidays. The piston, connecting rod and crankshaft came from a scrapped gas engine but the cylinder and other castings were new, made to HRR's drawings. Even at this young age, he was able to conduct his first fundamental research into internal combustion and in 1903 having listened to Sir Dugald Clerk referring to the concept of "stratified charge", was so motivated that he decided to adapt his engine to accommodate this new but challenging idea. However, achieving success with stratified charge remained elusive, as was the case with other researchers even in the following decades.

This engine has been restored and is currently on display at the Ricardo Shoreham Technical Centre, where in June 2010 an IMechE Heritage award was bestowed by the President of The Institution of Mechanical Engineers on Sir Harry Ricardo FRS, "in recognition of his life and work as one of the foremost engineers of the twentieth century". The Engineering Heritage Awards were established by the IMechE in 1984 to celebrate excellence in mechanical engineering through the

recognition of artefacts, locations, collections and landmarks of significant mechanical engineering importance. This engine now displays the Engineering Heritage Award commemorative plaque.

1907 – The Dolphin Two-Stroke Engine

In 1908 HRR's cousin, Ralph Ricardo, started a new business - "The Two Stroke Engine Company" - in a former boat shed in the fishing village of Shoreham-by-sea. The plan was to use a two-stroke engine, designed by HRR and patented in 1906, in a car called the Dolphin. It is interesting that HRR was a consultant in this association and not a business partner as such. Although he clearly had sound business sense and could see opportunities, he was really driven more by technology than raw commerce.

This two-stroke engine was rather unorthodox, in having two separate cylinders arranged in a 75 degree V (Figure 3). One cylinder operated on a normal two-stroke cycle with the other as a pumping/scavenging cylinder. The cylinders were linked with a cross pipe, transferring the compressed fuel/air mixture to the working cylinder. The combustion chamber "bulb" was so designed to exploit the advantages of stratified charge, mentioned earlier, enabling the strength of the charge to be varied without throttling. This approach allowed the engine to idle much more smoothly than other two-stroke engines at the time.

Figure 3. The two-stroke Dolphin engine.

The chronology of the engine, the car application and the fishing boat application is sometimes incorrectly described, and so the author would like to clarify this for the record. The engine had its origins back in 1902 and for the subsequent car project was to be offered in two versions – a single cylinder (actually looking like a V2) and a twin (looking like a V4 with the two pairs of

cylinders). At the start of the Dolphin motorcar project, this application was the principal one in mind. A prototype engine was built but at that time, the company was suffering financially and the car project did not look promising. A young Scot called Angus (his full name remains elusive) freshly joined the company and possibly without the blinkered view of a car business quickly saw potential for this innovative engine right under their noses (almost literally!) in the form of the Shoreham fishing fleet. The company premises were located alongside the river. Shoreham depended considerably on the fishing industry and the many small clinker open sailing boats were the main resource to bring in the catch. Adverse weather and strong local tides often compromised this important local livelihood. Angus made the radical suggestion that business could be diverted into something more profitable by equipping these small fishing boats with the two-stroke engine. And so, the business was re-focused and the car all but neglected while almost every fishing boat in the town asked for internal combustion power. The engine had many benefits but in particular was very good at running at low speed (120 rev/min) for long periods, an important requirement when using drift nets. The Dolphin car never really became established due to economics of production and the business finally closed in 1911, with Ralph leaving for new opportunities in India.

Figure 4 depicts a relaxed HRR around this period, in his twenties. (Note that this is not an illustration of the type of boat or engine referred to above! It is thought this picture was taken while he was on honeymoon).

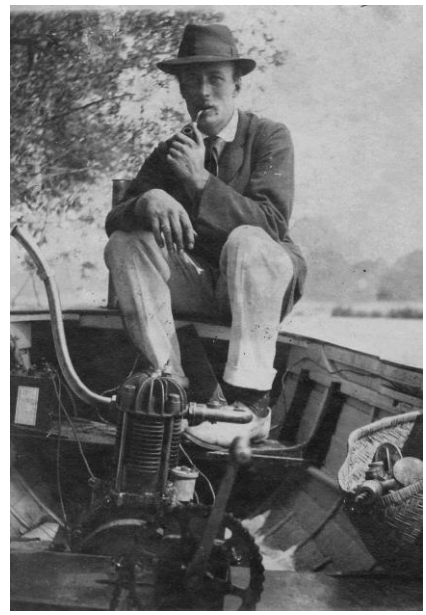

Figure 4. Harry Ricardo in his twenties.

1914 - WW1 Tank Engines

The background to this subject has been outlined earlier. However, it is worth mentioning some technical aspects of the engines and how they were so much improved. The original Daimler 105hp spark-ignition engines for the new "tank" concept suffered numerous problems, including inadequate splash lubrication of the internal bearings, and worse, the already-mentioned large amounts of visible blue smoke in the exhaust caused by the necessity to over-lubricate the sleeve valve system. This was a major flaw as it exposed the vehicle's position to the enemy. HRR was approached to address these problems, and did so in the form of a new 150hp engine incorporating what were state of the art features at that time – for example, cross-head pistons and masked inlet valves.

> In those days, there were no such things as oil control rings for pistons and blue smoke in the exhaust of all motor vehicles was a prevalent nuisance.

HRR had already designed and built in his workshop an experimental engine incorporating a crosshead piston design. The piston crown was isolated from the crankcase and very effective oil control was achieved; the exhaust was completely invisible under all operating conditions.

HRR had originally designed the engine for 200hp but 150hp was settled on (Figure 5) partly because of transmission limitations. However, towards the end of the war, a more powerful engine (225hp) was put into production but was too late to see service in France. The engines were manufactured by a group of seven companies, including Mirrlees, Crossley, Ruston & Hornsby and Gardiner and in fact could be considered the UK's first mass-produced internal combustion engines.

1920s - Shell & Pioneering Work into Detonation

HRR had his first contact with the Anglo-Dutch Shell Oil Company in 1917, during a high level Whitehall meeting to discuss the allocation of fuels to various services. At this committee level, the appreciation of the finer points of the effect of fuel type and quality on engine operation was rather limited and HRR at the time clearly found this frustrating. This must have shown, because the MD of Shell at the time, Sir Robert Waley-Cohen, took HRR aside after the meeting and quizzed him in more detail about fuel properties. HRR was already researching detonation phenomena in his personal workshop, using a variable compression ratio single cylinder engine. This impressed Shell and so started the relationship whereby Ricardo began testing samples of fuel sent to him. Very soon, Shell promised to support HRR's Engine Patents Company by committing £10,000 per year for a three-year programme on fundamental research into the problems of matching fuels to the various engine types (roughly equivalent to £360,000 per year today). This generous commitment together with the royalties from the tank engines enabled

HRR confidently to proceed with the building of his new facility at Shoreham-by-sea (Figure 6) and begin this vital pioneering work on fuel properties.

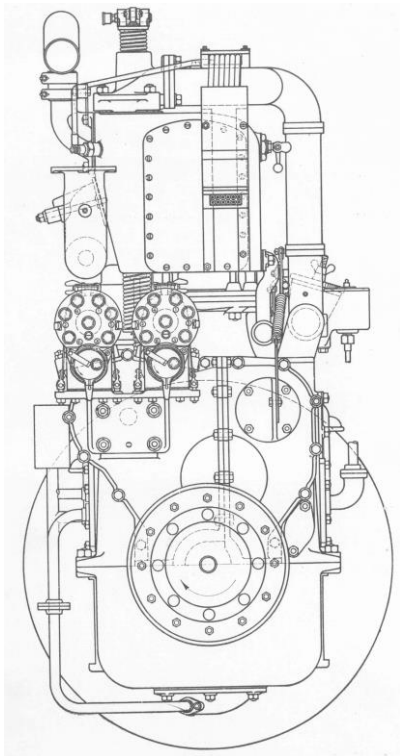

Figure 5 - 150hp tank engine

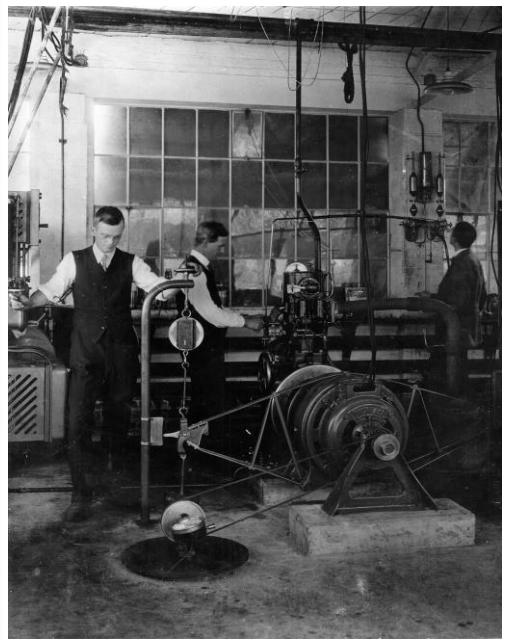

Figure 6 – Early "Bridge Works" test shops

1921 - First Four-Valve Engines – for Triumph and Vauxhall

Although side valve combustion systems were generally preferred in the 1920s for reasons of convenience and cost, HRR recognised that an overhead valve arrangement was far superior in terms of performance. He carried out much research into such systems in his home workshop at Walton. In the pioneering days of motorsport, the quest for performance led to advanced engine designs. It was in this light, that HRR developed a high performance single cylinder racing motorcycle engine based on the Triumph 500 (Figure 7).

A close colleague, Frank Halford, raced developments of this unit at Brooklands and their combined passion resulted in iterations of the engine and an output of 25hp at 5000 rev/min. These engines had pent roof combustion chambers with domed lightweight aluminium pistons and four valves. These were examples of some of the very earliest four-valve systems, originating for racing but which are now almost universal today in road cars. A de-tuned version was designed for road

use in the Triumph-Ricardo motorcycle, which was very successful, making "Ricardo" a household name and resulting in significant design royalties for HRR.

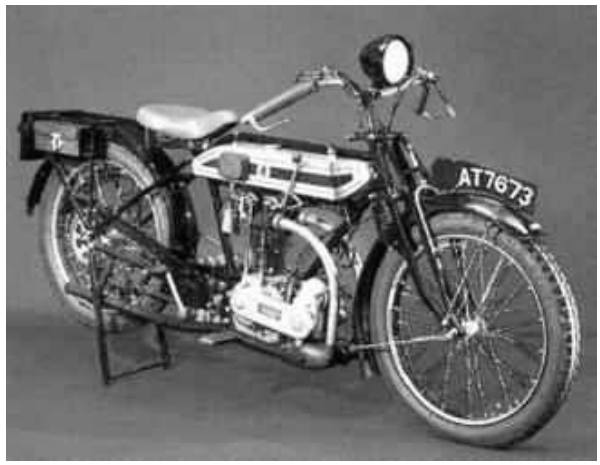

Figure 7. Triumph motorcycle.

HRR applied this very advanced four-valve concept to a four-cylinder three-litre Vauxhall racing car in 1921 and in 1922 three cars with these engines (Figure 8) were raced at the Isle of Man TT event.

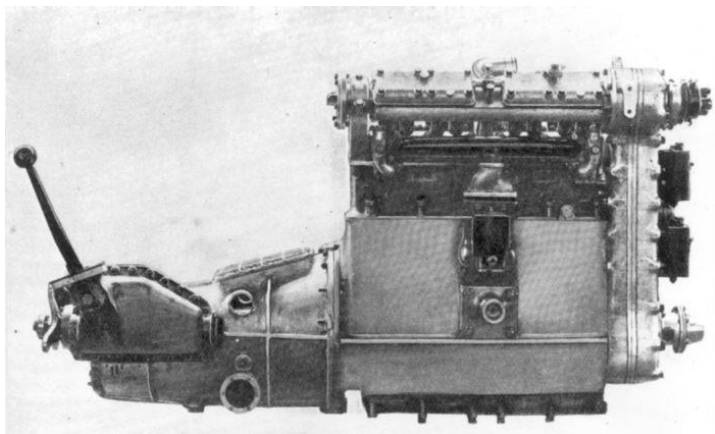

Figure 8. 1922 three-litre Vauxhall racing engine.

The Early Working Culture at "Bridge Works"

HRR was the true gentleman and perfectionist, searching for efficiency in engines and demanding similar performance and effort from his employees. John Reynolds describes the early culture of Bridge Works very well.

Evidently, not least among Ricardo's gifts was his ability to recognise engineering talent in others, and then to gather these men around him in a happy and harmonious environment, singularly free of tensions and rivalries. His ability to attract, recruit and retain high-quality staff was a key factor in his success, for once admitted into the Shoreham fold the chosen men tended to stay with him for years, thankful for the chance to develop their potential to the full without undue pressure or interference from on high. Indeed, it was not unusual for graduates entering Bridge Works straight from university to remain there for their entire working lives. In planning his laboratories as a young man, Ricardo had hoped to create a self-financing research establishment that would also be a training ground for young engineers, a centre of knowledge with an ethos more akin to a university college than an apprentice school. Clearly, he succeeded in this aim. He knew how to get the best out of the people working under him, advising rather than ordering them about, and he treated his staff as pupils rather than servants. Indeed, it has been said by many ex-Ricardo engineers that HRR was like a benign and benevolent headmaster, a much revered and magisterial figure, profoundly respected but never remote or unapproachable. He would condone no impertinence or familiarity, nor would be suffer indifferent or indisciplined work that failed to reach his own high standards, yet he was respected as an unfailingly courteous and considerate employer who ruled his Shoreham empire by example and encouragement and not by threat or coercion as did many other notoriously authoritarian leaders of the automobile and aeronautical industries in his day.[2]

1920s- Turbulent Head Developments

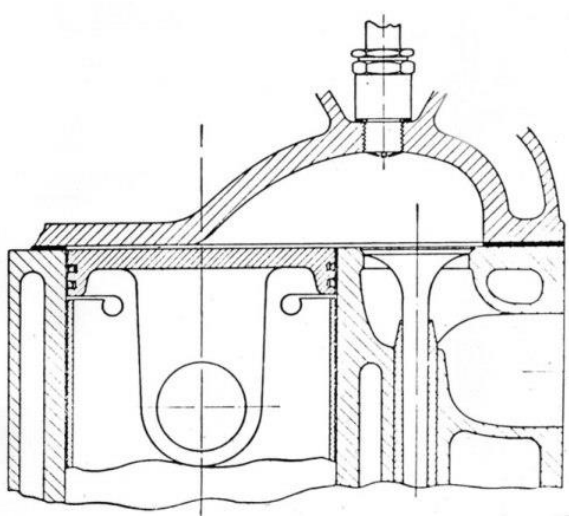

Figure 9. The Turbulent Head combustion chamber.

HRR readily appreciated the benefits of overhead valve combustion systems but was also aware of the potential and application of the cheaper side-valve engine in mass-produced motorcars. He therefore applied his knowledge of detonation resistance to the side valve engine and developed and patented what was known as the "Turbulent Head" (Figure 9). Engines using this system could achieve significant improvements in performance and fuel economy (of the order of 20%) and raised the humble side-valve engine up to the levels of overhead valve engines of the time. The Turbulent Head became popular in many applications and yielded significant income from royalties. One estimate suggests some £40,000 was obtained in royalties from this patent in the period 1919 to 1932. This would be equivalent to about £1¾ million today.

The Le Zebre Car

The Le Zebre car was initially designed by Ricardo in 1922/3 and built by Automobiles Le Zebre, near Paris. The turbulent head combustion system, referred to above, became popular in France and the Le Zebre was the first application in that country. HRR not only designed the two-litre four-cylinder side-valve engine but also, unusually, the chassis, running gear and body work. The Le Zebre Company produced cars from 1924 to 1930 and HRR used one as his family car for many years, taking the opportunity to tour parts of France. Some 550 cars were produced in total and so these days running examples of the car are extremely rare. However, one was identified in France some years ago, purchased and fully restored at the Ricardo Company to working order in 1995-6. HRR's only surviving daughter, Camilla, has since had opportunities to re-live her childhood days by being able to ride in the restored car at the occasion of the commemoration of HRR's London birthplace with a Blue Plaque by English Heritage in 2005.

Protecting the Business – Pirates and Litigation

Although HRR enjoyed an early business life of contented innovation and technical motivation, it was not always easy. Being highly ethical and of such a gentlemanly nature, he was very disturbed when his patents were beginning to be infringed. At one time, this was a common occurrence and tended to be reluctantly overlooked but there were situations where the piracy was just too much to bear and court action was needed. An example of this was the extensive copying of the Turbulent Head combustion system, referred to earlier. In the late 1920s, cars were being manufactured in the USA with this system and imported into the UK. There came a time when it was realised that an example had to be set and so in November 1931 a writ was issued against Humber-Hillman (owned by the Rootes brothers) alleging patent infringement. As HRR put it:

> It was all the more important for us to make it clear that we were prepared to fight for the sanctity of our patents, past, present and future.

The court hearing took place on October 1933 and found in favour of Ricardo. There was clearly some debate about how or if to use HRR as a witness; in the end he was examined at length in the witness box for some two days – apparently in an atmosphere of friendliness and good humour. HRR recounted how his counsel eloquently set the scene:

> He explained to the judge that we were not manufacturers but a research team and, as such, depended upon royalties from our patents to finance the research that we were carrying out on behalf of industry as a whole, and that our objective in bringing the case to Court was to establish the sanctity of one of our patents and that it was far from being our intention to hold up the British motor-car industry to ransom.

Over the subsequent years Humber-Hillman, and a number of other companies including Ford, settled, with Austin and Ford taking the longest time to finally agree.

The author only mentions this subject as a means of illustrating HRR's non-litigious nature. This sort of caddish behaviour he found difficult to tolerate and situations like the above did put pressure on his otherwise happy family life and must have been a frustrating distraction from getting on unhindered with his day to day business of research and development. Figure 10 shows HRR in his early forties around these difficult times.

Figure 10. Harry Ricardo in his forties.

1930s – Early High Speed Diesel Research & the Evolution of the "Comet" Combustion Chamber

HRR was well aware of the potential for high speed diesel engines, from shortly after the First World War. At that time, there was interest in the possible application of diesel engines to long-range and patrol aircraft but finally after some considerable research using single cylinder engines, it was concluded that spark ignition offered more benefits, despite the unpopularity of the volatile fuel. However, HRR still saw considerable potential for small "high speed" diesel engines in road transport and started to formulate ideas in the late 1920s. What transpired must rank as one of the most important developments in Ricardo early history – the Ricardo Comet was born. HRR was well aware of the need for swirl to create effective mixing of the fuel and air. Analogies of "hose pipe in a bucket" come to mind and this sort of picture was no doubt the basis for his thoughts and imagination. He achieved the swirl he needed, without the benefit of high-speed photography inside the chamber and advanced simulation software, which were to come much later, by means of a swirl-creating pre-chamber combined with flow directing profiles in the piston crown. The patent application date for the first Comet combustion chamber was June 1931 (Figure 11).

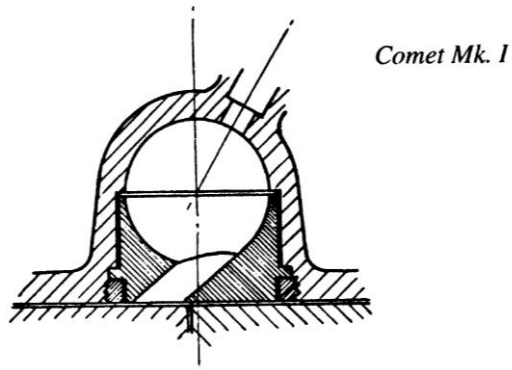

Figure 11. Cross section of first Comet IDI diesel combustion chamber.

By the late 1930s, the Comet had evolved into improved marks through subtle changes in the chamber geometries and injector/heater plug orientations and in further years ultimately became the Mk Vb. Some Comet chamber patents remained in force until 1975-80, depending on the country. By the 1970s, virtually all diesel cars were using the Comet system (either legitimately or copied) – the one exception being Mercedes Benz, who persisted with their own rather different pre-chamber concept. All these systems, however, were to become obsolete in car applications with the introduction of the more efficient direct injection system, made possible by rapid developments in higher pressure fuel injection systems.

However, many years later, in 1996, a major car company was interested in extending the benefits of indirect injection further in the light of potential emissions benefits and the Ricardo Company was contracted to develop what was perhaps the final iteration of the chamber to successfully achieve Euro 3 emissions in a light truck. With the benefits of in-house computational fluid dynamics software together with many decades of experience, some of the fundamental "rules" of the Comet design were re-directed and an evolutionary new design created – aimed essentially at meeting stringent exhaust emission standards. This created significant challenges for the team at the time but finally resulted in complete achievement of every target set by the customer.

1935 – The Citroen Rosalie Diesel Car

In November 1932, HRR received two senior ambassadors from Andre Citroen's prestigious company. This precipitated an important alliance and friendship that developed over the next two years, with Andre Citroen making his first visit to Bridge Works in 1933. He had long realised the potential for diesel power in passenger cars but did not have a suitable engine. Thus the alliance was formed whereby a Ricardo Comet-based, 1.75 litre four-cylinder engine was designed and built and by 1934 prototypes were running to the "complete satisfaction" of the Citroen founder (Figure 12). The application was the Citroen Rosalie and the first known example of the car was submitted to the French road transport authority for type approval on 27 November 1934. In 1936 between fifty and seventy-five examples of the Type 10A Rosalie taxi had been loaned to selected customers for in-service trials. These were subsequently sold and so the Citroen-Ricardo diesel car became the world's first diesel powered passenger car to be marketed to paying customers, preceding the competition, in the form of the Mercedes 260D, by almost a year. At the time, the French press poured praise on the car, commenting on the flexibility, reliability, smoothness without smoke and "overwhelming" fuel economy benefit.

Figure 12. The Citroen Rosalie diesel car.

In 1992, an original Rosalie engine was found in a store at the Ricardo Company and a chassis identified and purchased. During 1992-93 the car was fully restored to working condition and remains so today.

1936 – Flying Spray

George Eyston, one of the early brave pioneers of racing and speed record breaking, had already gained experience in 1933 with a diesel powered car, setting a new speed record of 104.86 mph at Brooklands. He went on to greater challenges in 1936 by achieving a diesel speed record of 159.1 mph in a car called the Flying Spray (Figure 13). This car used a Ricardo 19.2 litre V12 sleeve valve four-stroke diesel conversion of the Rolls-Royce Kestrel engine. HRR was always very keen on motorsport applications, using the development experience in the quest for performance and efficiency – two of the principal goals in today's motorsport challenges.

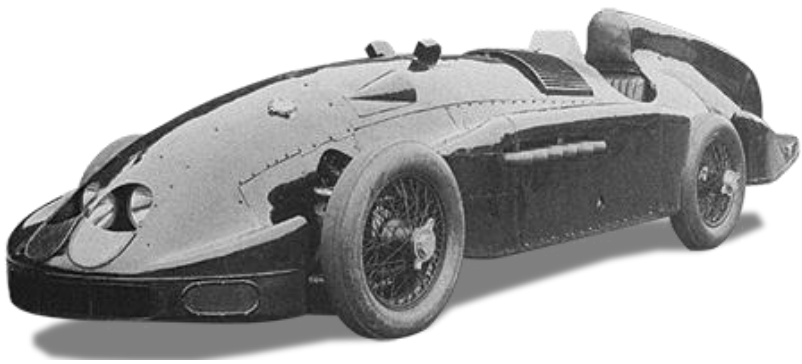

Figure 13. Flying Spray diesel land speed record car.

1940s – Rolls-Royce Crecy

Throughout this paper it has been shown that HRR had very wide interests in all forms of engines and this section on the Rolls-Royce Crecy aircraft engine is included to illustrate this point. However, the spirit of this particular project somewhat contradicts the paper's title in that the goal in this case was ultimate performance rather than efficiency. At the start of 1936, in HRR's report to the Air Ministry Engine Sub-Committee, he wrote:

> The present note relates to the possibility of developing a special-purpose aero-engine of very high performance for short flights only, without the usual regard for fuel or oil consumption, but in which high specific output and small frontal area are taken as being the dominating conditions.

The engine was to be based on a spark-ignited conversion of the Ricardo E44 diesel two-stroke sleeve valve engine, with direct fuel injection. With design and testing support from Ricardo, Rolls-Royce built and developed from this concept a supercharged V12 version, designated "Crecy", as it had been the tradition at Rolls-Royce to name their two-stroke engines after famous battles (Figure 14). The twenty-six litre engine had various peak ratings that ranged from some 1700 hp to over 2700 hp. To demonstrate the potential of the engine, a single cylinder engine was later run at Ricardo and produced an equivalent output of 5000 hp. This was indeed a real sprint engine of prodigious rating. With developments in gas turbine engines threatening its future, however, the Crecy project was finally abandoned in December 1945. At the time, the Aeronautical Research Committee report stated:

> Research had revealed that the two-stroke sleeve valve cylinder was capable of maximum power of nearly double that of contemporary four-cycle engines, nearly 200hp/litre….. It seems probable that, had the turbine not materialised, the two-stroke would have proved the next step in the development of the aero engine.

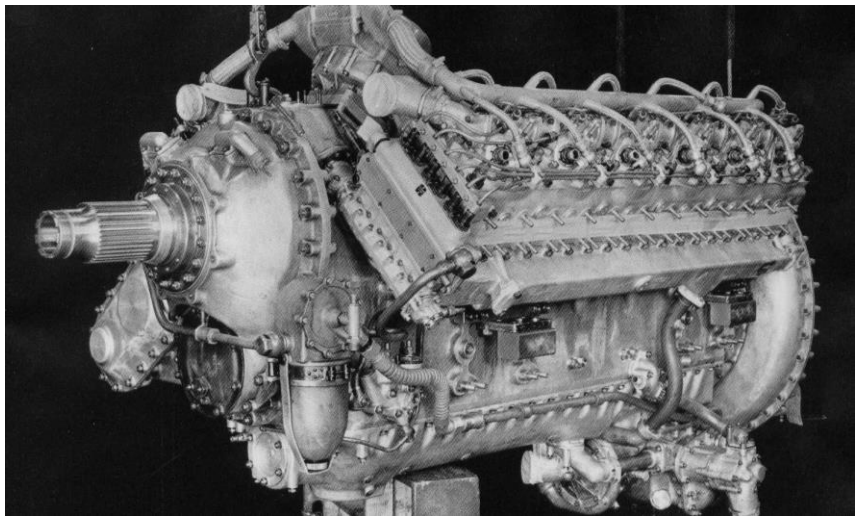

Figure 14. Rolls-Royce Crecy engine.

1950s – Fell Locomotive Engine

HRR by no means had a blinkered view of the transport industry. He was interested in all aspects of transportation which presented technological challenges – on the road, in the air, at the race track and on rails. One unusual project to illustrate this point, therefore, is the Fell diesel-mechanical locomotive. Up to this point, the transmission of the huge power and torque from diesel locomotive engines had to be tamed via electric generators and motors ("diesel-electric"

systems). The unique aspect of the Fell locomotive was achieving direct traction via a novel transmission, devised by L.F.R. Fell. This resulted in significant weight saving and better efficiency by avoiding the losses inherent with the electrical system. Once again, HRR was involved in a groundbreaking project with efficiency objectives. The first locomotive was demonstrated in 1951 (Figure 15). The project was conducted through a consortium of companies with Ricardo acting as design and development consultants. The main propulsion engines were four Paxman-Ricardo V12 units, each developing 500 hp. Hydraulic couplings to a central gearbox incorporating three epicyclic differentials linked these engines.

There were various reasons why the locomotive never saw extended service – some political – but it did see eight years of active service before being scrapped in 1960.

Figure 15. The Fell locomotive.

From inside the Combustion Chamber

In 1931 HRR delivered a paper titled "Diesel Engines" at the Royal Society of Arts in its Howard Lecture series and he invited the audience rather unconventionally to accompany him inside the cylinder of a diesel engine.

> Let us imagine ourselves seated comfortably on the top side of the piston, at or about the end of the compression stroke. We are in complete darkness, the atmosphere is a trifle oppressive, for the shade temperature is well over 500 °C – almost a dull red heat – and the density of the air is such that the contents of an average sitting room would weigh about a ton; also it is very

> draughty, in fact, the draught is such that in reality we should be blown off our perch and hurled about like autumn leaves in a gale. Suddenly, above our heads a valve is opened and a rainstorm of fuel begins to descend. I have called it a rainstorm but the velocity of the droplets approaches more nearly that of rifle bullets than of raindrops. For a while nothing startling happens, the rain continues to fall, the darkness remains intense. Then suddenly away to our right perhaps, a brilliant gleam of light appears moving swiftly and purposefully; in an instant this is followed by a myriad others all around us, some large and some small, until on all sides of us the space is filled with a merry blaze of moving lights; from time to time the smaller lights wink and go out while the larger ones develop firey tails like comets; occasionally these strike the walls, but being surrounded with an envelope of burning vapour they merely bounce off like drops of water spilt on a red-hot plate. Right overhead all is darkness still, the rainstorm continues and the heat is becoming intense; and now we shall notice that a change is taking place. Many of the smaller lights around us have gone out, but new ones are beginning to appear, more overhead, and to form themselves into definite streams shooting rapidly downwards or outwards from the direction of the injector nozzles. Looking round again we see that the lights around are growing yellower; they no longer move in definite directions, but appear to be drifting listlessly hither and thither; here and there they are crowding together in dense nebulae and these are burning now with a sickly smoky flame, half suffocated for the want of oxygen. Now we are attracted by a dazzle overhead, and looking up, we see that what at first was cold rain falling through utter darkness, has given place to a cascade of fire as from a rocket. Above and all around us are still some lingering fireballs, now trailing long tails of sparks and smoke and wandering aimlessly in search of the last dregs of oxygen which will consume them finally and set their souls at rest. If so, well and good; if not, some unromantic engineer outside will merely grumble that the exhaust is dirty and will set the fuel valve to close a trifle earlier. So ends the scene, or rather my conception of the scene, and I will ask you to realise that what has taken me nearly five minutes to describe may all be enacted in one five-hundredth of a second or even less.[3]

The author makes no apologies in quoting at length from this milestone paper as it is such an apt reflection of HRR's imagination, which steered his technical designs and understanding of internal combustion.

Famous Names & Travel

In his long career, HRR met many other engineering pioneers of their time. Some visited the Shoreham facility. The list is extensive, but highlights are Andre Citroen, Henry Royce, Frank Whittle, Herbert Austin, Roy Fedden; he even had a close friendship with his neighbours Rudyard Kipling and his family.

He travelled extensively in Europe, the USA and Asia and no doubt took opportunities from the relatively relaxed and slow journeys to ponder on new ideas

and make the odd note – all free from the bombardment of today's continuous communications and distractions. Jack Pitchford, former Chairman of the Ricardo company and a very close friend of HRR, recounted how in his travels it seemed that HRR had a closer association and was held in higher regard by "continental" colleagues, rather than British. He added:

> In all these early post-war contacts with senior engineers in France, Germany, Italy and elsewhere I was immediately made aware of the extraordinary esteem and regard in which Harry, as a person, and the importance of his work, was held.

Recognition, Medals and Roles

HRR was made a Fellow of the Royal Society in 1929 and knighted in 1948. He was awarded many medals in his lifetime as well as honorary degrees and served as President of the Institution of Mechanical Engineers in 1944. In 1995, he was invited to give the Horning Lecture to the American Society of Automotive Engineers. Figure 16 shows HRR in his sixties.

Figure 16. Harry Ricardo in his sixties.

Harry Ricardo – the Man, his Family and Hobbies

In 1911 Ricardo married Beatrice Bertha Hale, an art student at the Slade School of Art, in London. Her father, Charles Bowdich Hale, was the Ricardo family doctor. They had three daughters – Kate, Angela and Camilla.

The first family home was in Walton-upon-Thames but they moved to what was then rural Lancing in 1919 when "Bridge Works" became established at nearby Shoreham-on-sea in West Sussex. HRR liked the solitude and peace of the countryside and so became less than happy with the urban developments at Lancing. In 1933 they decided to up-root.

> All the charm of the countryside was fast disappearing and my wife and I scoured the neighbourhood in search of a new home.

They eventually found, for the sum of £7000 (equivalent to £350,000 today) "a small but very charming old manor house of Elizabethan origins". Tottington Manor was in effect a small agricultural estate of about 250 acres with woodland, outbuildings and two cottages. This wonderful environment gave HRR all the opportunities he needed to pursue his love of nature, butterflies, growing plants and unusual fruits. He devised a floating greenhouse dubbed "The Queen Mary" which they could easily move along water channels to expose or shield plants from the weather. His passion for efficiency (he could not bear waste or extravagance), is illustrated by his use of the hot water remaining from baths and washing, which was not just ditched in a drain but first passed through heat exchangers in the greenhouse - in this way he was able to grow nectarines, rather unusual for the day in that part of England – and also by his use of the otherwise wasted energy from garden bonfires to heat a large container of water which in turn was used to heat the greenhouse.

As war developed, in 1940 the family left Tottington and moved to Oxford. The house was requisitioned and the family never returned. (In much later years it became and still is an hotel.) After the war the family moved to his parent's former home at Graffham in West Sussex, where HRR lived until his death in 1974.

In addition to his botanic interests, HRR was also keen on the music hall and light opera (especially in his bachelor days) and boating - a major hobby with the convenience of being very close to the sea. He acquired a number of interesting craft over the years – both sail and power.

The author was the last employee at Ricardo who had the privilege of meeting HRR in the early 1970s. At that time, in his late eighties, he still visited the company and would sit in his office and invite conversation especially from the younger engineers. The author at that time had just started at Ricardo and was working on a project to develop a very advanced steam engine - an "expander" as the US customer termed it. This was at the time of the start of interest in exhaust emission control and the steam engine offered such benefits – but at a cost. To

ensure something like acceptable efficiency, the steam pressure and temperature had to be unusually high (of the order 70 bar and 500ºC). HRR was most interested in this and as the senior staff was generally too busy to spend much time with him, the author was privileged as a junior engineer to be asked to meet him and explain this novel technology. He could barely see drawings but his unsteady wavering finger homed in on the critical part of the design - the steam admission system - controlled by two small poppet valves in series, operating via a phase changer and having to withstand these extreme pressures and temperatures. "You're going to have trouble with the valves….." he explained, in his faltering but authoritative voice. We certainly did – this turned out to be the Achilles heel of the whole design, which nearly collapsed due to this particular arrangement. He had spotted this so quickly. Figure 17 shows HRR at about this time.

Figure 17. Harry Ricardo in his eighties.

In his later years, he did suffer from increasing deafness and deteriorating vision, impeding normal conversation in a man already admitting to being naturally

shy. In 1968 he wrote to his colleague, Percy Kidner (a former board member and well respected President of the Institution of Automobile Engineers) remembering his gratitude for the support Kidner gave HRR in the difficult litigation days. The letter gives a vivid illustration of HRR's incredibly modest, gentlemanly character:

> I am afraid that my performance at our lunch party was very inadequate. All my life I have suffered from the defect that, once my emotions are stirred, I become completely tongue-tied, and quite unable to express my real feelings. There was so much that I would have liked to say about all the help and encouragement you gave me in the very early days… but the words just wouldn't come out…… Ever since I first met you some fifty years ago, I came to regard you as a guide, philosopher and friend; throughout I have felt that you and I shared the same philosophy of life but you provided the experience and sound judgement which I lacked; more especially did I realise this during the anxious period of our Patent Action and its aftermath when you did so much to steer us through that difficult time….. All this I would have liked to enlarge upon, but too much emotion deprived me of speech.

HRR smoked heavily. His daughter, Camilla, recounted family outings in the Le Zebre car when HRR would be forced to stop from time to time to clear a carburettor blockage by tapping the bowl with his pipe, which was rarely from his grasp. He continued to smoke right up until his death – traditionally a pipe, but in later years, un-filtered Camel cigarettes, cut in half, and so tricky to light, given his shaking hands and proximity of his white moustache! But it was not that which finally laid the great engineer to rest – he suffered a fall and pelvic injury, which although not initially fatal, required operations from which sadly he did not recover.

It could be said that a scientist lives with perfection but an engineer with compromise. An engineer has to make the best practical use of the available resources and HRR certainly did that. He was a true gentleman, polite, respectful, energetic, immensely resourceful and highly imaginative.

Conclusion

From the start, HRR had his sights set on establishing a leading research and development group, pioneering new and improved ideas for improving transport efficiency as well as nurturing and developing some of the best young brains in the industry. He would be proud to see how this thread has persisted in the company to this day, with the accent so much now on energy conservation, sustainability and low emissions – all the attributes he passionately pursued. He would have been fascinated with the complex modelling and simulation tools now taken for granted and which he was only able to dream of. Without such aids, he nevertheless achieved remarkable successes through his incredible imagination, technical vision and spirit – he was a man before his time.

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Much of the material used in compiling this paper has come from Ricardo publications, personal sources, the Ricardo family and two particular books, referenced below, by John Reynolds and Dr Andrew Nahum who have both kindly given permission for the use of material from these books.

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Notes on Contributor

The author joined Ricardo in 1971, having read Mechanical Engineering at Loughborough University and completing a 2-year VSO engineering teaching project in West Pakistan. He has worked in Alternative Powerplants and Client Services, before moving to the Noise Control Laboratory, and re-formed it into The Refinement Centre. From 2000 to 2005 he established Ricardo Japan Ltd. He also initiated and helped form a consolidated Ricardo Motorsport group in 2000, and as senior operations manager was involved for 10 years. He retired in June 2010 but continues in a part-time contractor role, mainly on motorsport engineering business. In 2010 he was invited to take on an additional and separate role as part-time motorsport consultant to the newly created company "Coryton Advanced Fuels". He was the last employee at Ricardo who had the privilege of personally knowing Harry Ricardo through conversations about projects.
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