Prospectus

For

The K6 Engine Development

Phase 2

Prototype Production & Testing

K6

Authors:
Owen Jordan & David Gibson

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1. The Parties

The parties currently involved in the K6 engine project are as follows:

- Jordans Consultancy – Owen Jordan – Lead designer
- Railfast Intermodal – David Gibson – Project manager
- Richard Coleby – Independent consulting engineer.
- University of Birmingham, UK. Department of Engineering: Professor M. L. Wyszynski (thermodynamics); Professor F. Schmid (engineering)

The University of Santa Catarina (Florianopolis, Brazil) is not currently active in research, but has one postgraduate student completing his PhD on a research topic directly related to the development of the engine.

The project has been run on an 'at risk' basis by all participants: there is no formal contract between the parties at this point.

The lead designer and project manager assert they are able and willing to enter into a suitable formal contract with any prospective partner to secure the rights of that partner to a share of the intellectual property commensurate with their contribution.

2. Executive Summary

Phase two of the K6 engine project is intended to take the design of the engine forward, from electrically powered model to completion and testing of a working prototype.

The K6 engine has been designed as a single cylinder, two piston, rotary-reciprocating unit operating on a two-cycle basis. This is the simplest form of the K6 concept, which includes a minimum number of components (c120Nr). The key concepts are the non-sinusoidal motion of the pistons in the cylinder, the stator, and the moving injector in the combustion chamber.

The K6 engine, as designed, has a nominal swept volume of 1.3L (102 bore x 80 stroke), gives two power events per revolution of the single cylinder, and has a maximum designed initial output of 80 – 100kW. Predicted operating speed range is c60-6000rpm.

The K6 concept also covers alternative arrangements that would provide for a four stroke cycle from the single cylinder and more than two power strokes per revolution. These are, however, outside the current proposal.

The Proposers are seeking funding/design/manufacturing partners for the completion of the detail design and production and testing of the prototype. Those partner(s) may be funders only, or possess some or all of the technical and manufacturing capacity on their own part.

The Proposers are able and willing to enter into a suitable contract in exchange for an allocation of a portion of the IP rights of the K6 engine.

The Proposers are prepared to offer project management and other management services as part of their contribution to Phase 2, and Richard Coleby has indicated that he is prepared to contribute further to the project as consulting engineer.

The project is anticipated to be of two and a half years duration and will include completion of detail design, as well as manufacture and testing of the prototype.

Project costs are anticipated to be in the order of £0.9m at current prices for the works to completion of phase 2.

The project is intended to produce results for the purposes of enabling the K6 to be designed into products that will sell into both new markets and into any of the current markets for portable and fixed power. It is anticipated that partners in this project will want to set up parallel projects as phase two proceeds, to design products and secure markets that will take advantage of the K6's merits.

The planned duration of phase two is based upon the unique concept of the K6 compared to existing units; no engine of this type has ever been produced. It is anticipated that the design staff who will work on the project will take some time to familiarise themselves with both the unusual nomenclature, and with the specialised physics that underpins the key innovations.

The wider issues of the K6 are discussed in the text. The reciprocating IC engine, like the steam engine before it, changed the world. It is quite probable that the K6 will, too.

3. The Project

The K6 is an engine utilising the rotation of two bodies (cylinder and piston) about separate centres to generate reciprocation of the piston(s) in the cylinder. It is defined as a 'rotary-reciprocating' engine (Wyszynski 2016). The operating principles and effects are described below.

The K6 engine project is seeking to move from theoretical design to production and testing of a full size working prototype, and is seeking partners with the technical, financial and production resources to take the project to and through that stage. It is anticipated that the work will be split into three sections, viz:

- The completion of the design and working drawings
- The manufacture and assembly of the engine
- Testing, to establish its performance parameters and solve any design issues

The K6 engine development currently comprises two main threads: the theoretical analysis being undertaken by the Universities and aimed primarily at thermodynamic performance, and the mechanical design of the short engine (rotor, stator and frame), which is substantially complete and forms the basis of the electrically powered model.

Works to completion are thus anticipated to fall into the following areas of activity:

- Completion of design of the rotor to stator seal (currently proposed as a labyrinth)
- Materials specification (and any detail alterations consequent thereon)
- Stress analysis check
- Confirmation of the design of the air handling aspect of the main rotor
- Completion of design of the air filter, oil supply and oilway arrangements
- Manufacture of components and their machining
- Assembly, including fitting of a fuel injection system (anticipated as 'off the shelf')
- Testing and feedback into future production models

The works may also include the design of an engine-specific injector, but it is anticipated that this will not be an absolute requirement in the production of a working engine.

It is anticipated, but not guaranteed, that the University of Birmingham will be available to any partner for consultation, and will make available, or consent to the making available, of any and all existing documentation in respect of research undertaken to date. It is anticipated that the University may reserve the right to charge for its services, but to date has not done so.

4. The Contract

Prospective partners may propose any formal contract they deem appropriate for the purpose, and the lead designer and project manager may make any arrangements on their part to enable them to form a suitable company or other organisation to contract with the prospective partner. The lead designer and project manager advise that currently the Intellectual Property rights are covered by a UK patent application (PCT/GB/2017/050828) in the name of the lead designer.

The prospective partners' attention is drawn to the Rights of Third Parties Act in respect of the University of Birmingham and Richard Coleby, neither of whom will be formal partners in any joint enterprise so formed. The lead designer and project manager assert that they have no interest in any contract between those parties and any prospective partner, should those parties wish to enter into any separate agreement, beyond a requirement that the partner agrees to keep the lead designer and project manager fully informed of any intentions and actions on their part in that respect (full disclosure).

It is anticipated, and the UK patent application so drawn, that substantial IP opportunities will present to any partner. To date, the University of Birmingham (UK) and the University of Santa Catarina (BR) have expressed no interest in IP rights on their own part. The lead designer and project manager can however offer no guarantee to prospective partners that this will remain the case.

The prospective partners will agree, as part of this contract, to the completion of the IP protection of the K6 engine, and their joint status in regards to that protection, to ensure that the parties' interests are protected world-wide.

The lead designer will, on signature of the contract if not before, present to the partner in electronic format all documentation in respect of the K6 project that he believes relevant for the project, and undertakes to answer, or provide without undue delay, any further information requested that is within his ability to so deliver.

5. The K6 Engine

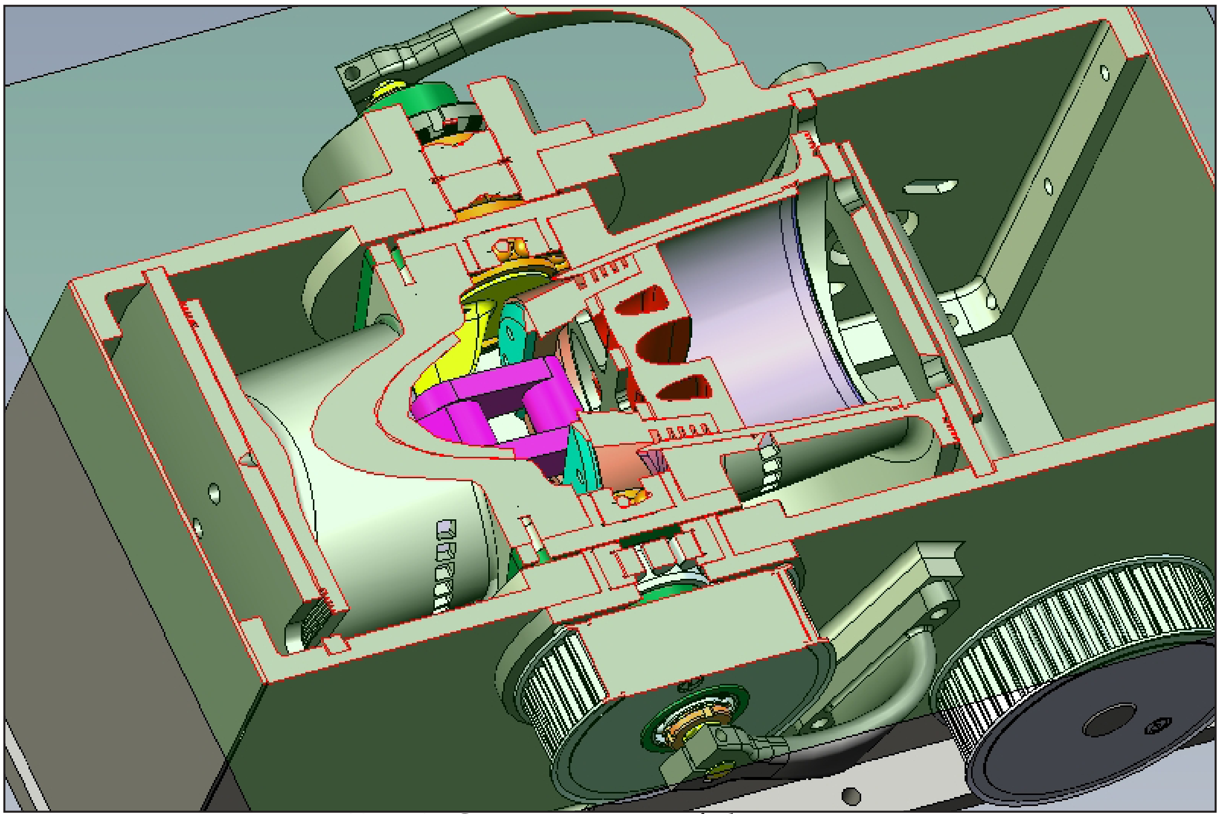

Fig. 1: Cutaway view of the engine

5.1 Historical

The principle of 'rotary-reciprocation', that is, the use of two separate centres of rotation to secure reciprocation of a piston in a cylinder, is believed to date from c1780, and does not appear to have been subject to any application for patent protection. Its first, and to date only, successful application to the internal combustion engine was by the Seguin brothers in the period 1905-20, who developed the 'Mono' rotary aero engine that dominated the skies of the Western Front in WW1. These included the Sopwith 'Camel' and 'Snipe' of 1916-18

'Rotary-reciprocation' is one of four known methods of translating the rectilinear motion – back and fore action – of a piston in a cylinder into useful work. Direct action via a piston rod is still in use, but parallel motion and the use of a rocking beam – the original concept dates from c1720 – is obsolete, the last units in the West being decommissioned in the 1960s. The dominant modern method of a crankpin or crankshaft tied to a wheel also dates from c1780, and has superseded all others. The theoretical effects of these different motions on the thermal efficiency of engines utilising them has long since ceased to be seriously considered.

The reason for that dominance is simplicity, coupled with its association with the rapidly increasing power density of engines in the twentieth century. This led to massive design efforts aimed at remedying some of the major issues – piston G-forces for example – that presented. The now conventional reciprocating internal combustion engine, in all its forms, has been the subject of more development work than any other item in the history of mankind: twelve decades of breakneck effort that has been at the core of the industrial world.

5.2 The K6 Concept

The K6 is a development of the 'York', an initial proposal for an engine to replace conventional reciprocating motion in a concept twenty first century steam locomotive design for Winnings Trains Ltd. The operating principle of the K6 is that of 'rotary-reciprocation': two key items, the rotor and the stator, are at the core of the K6. Resolution of the mechanical details allows the engine to be reduced in size from the York steam concept and given the power density to compete in the IC market. Of these details, it is the stator that allows the elimination of almost all of the mechanical complexity normally associated with an IC engine, such as camshafts and valves, etc. The stator enables the performance of multiple functions to be taken up by one simple component, and results in the moving injector.

Development of this idea was predicated on a detailed understanding of the rotary concept. Both cylinder and pistons in a rotary engine rotate about their respective centres; this is axiomatic, but by no means widely understood. Many modern explanations of the Seguin-type engine use conventional nomenclature, which is misleading at best. Furthermore, these explanations frequently fail to make explicit the key differences between a radial engine and a rotary engine, despite their differences being just as great as those between a rotary engine and an in-line engine. The design of the K6 necessitated a deeper understanding of the concepts involved, and, as the team soon discovered, simply trying to design a rotary engine without full knowledge of the motion proved impossible.

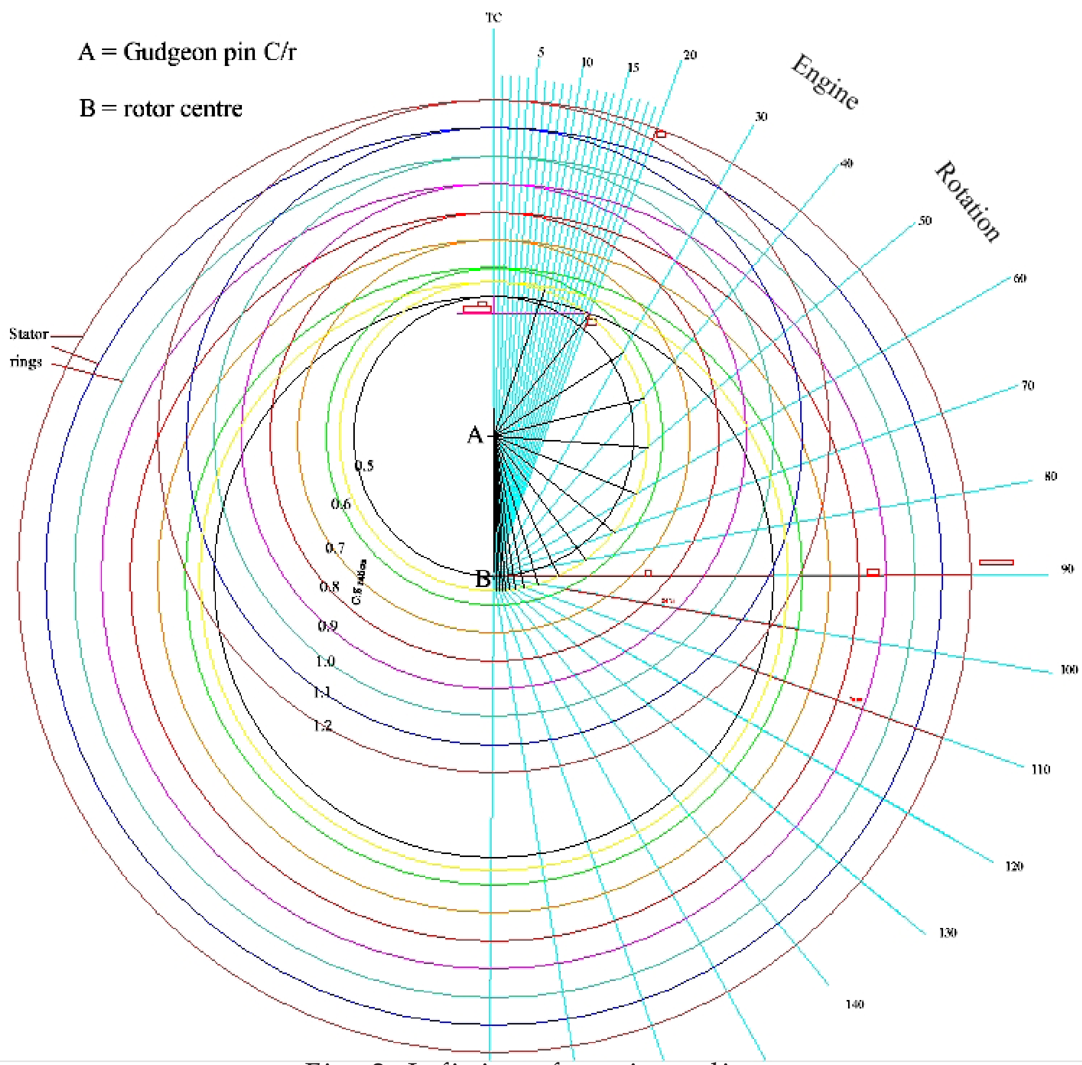

Fig. 2: Infinity of motions diagram

That knowledge deficiency on the part of the designer at the earliest stage proved to be of inestimable worth; it compelled a period of research and generated the 'infinity of motions' diagram. This diagram (above; p. 8) charts all the main possible motions of a K6-type rotary engines and allows piston stroke at any point in the motion to be simply measured off the diagram itself. This diagram enabled a critical analysis of the motion of a rotary engine and its critical parameters; the importance of this process cannot be understated. All piston-in-cylinder engines have what is known as a 'conrod:stroke' (C:S) ratio, the length of the conrod compared to the piston stroke. In conventional practice it is always more than unity[1], and usually about 1.5 to 2.5. At these ratios the motion of the piston is essentially sinusoidal. With the rotary engine, even at C:S ratios of unity, the motion is non-sinusoidal. At the limit C:S value of 0.5 – impossible in conventional engines – motion completes in 180deg of rotation – from 270ATC to 90ATC. The rest of the time the piston sits at bottom centre and simply rotates about its gudgeon pin.

Between the limit value of 0.5 and the point at which the rotary motion begins to close with conventional reciprocation (at about 1.2), are a whole host of C:S ratios, each of which have their own, absolutely unique, curves of motion. The K6 was eventually designed with a ratio of 0.55, after serious consideration of C:S ratios of 1.0, 0.75 and 0.6. The prime reason for this low ratio was the power density of the resulting engine; it keeps the rotor, stator, and the frame plates small. This resulted in a 300mm diameter rotor for an engine with an 80mm stroke, which we viewed as sufficiently small to keep the production costs of a prototype to a minimum. Yet with 100kW at predicted peak output, this design was also big enough to be in the mid-range of a market that runs to production of c100m units/p.a.

Mechanically, the K6 resolved into a compact unit of surprising simplicity: one cylinder, two pistons, one rotor, one each of stator and piston axle, two very short (44mm) conrods and a pair of frame plates to act as structure and air handling. Half a dozen bearings and bolts hold the engine together, without the need for internal bolt-up assemblies. The conrods have no split big ends, and the gudgeon pins and axle bearings are the same size. The piston axle has no torsional stresses of other cylinders to deal with, nor any energy exchange with a large remote flywheel. The rotor itself acts as the 'flywheel' and the pistons bear directly upon it; energy exchange as the pistons adjust their angular speed is simple, efficient, and vibration-free. The mechanical simplicity thus allowed for a design comprising approximately a hundred parts in total. However, as the following subsections detail, its thermodynamic characteristics proved to be far from simple.

1 A radial engine, where the cylinders are stationary, drives via a crankshaft (which is thus the output shaft). Radial engine pistons and cylinders do not have any circular motion, relative or absolute. A rotary engine drives via the cylinder(s),and does not have a crankshaft, but a piston axle, around which the pistons rotate in true circular motion, albeit subject to changes in angular speed. The K6 cylinder could be stationary, but it would not be a rotary engine, and that would deprive the engine of both its unique motion and the functions performed by the stator, which are critical. Elimination of the piston circular motion, and thus the relative motion of the combustion chamber and injector would result in the K6 ceasing to be a rotary engine; it would then display all the unwelcome aspects, such as piston g-forces, of a conventional engine.

5.3 Thermodynamics, Fluid Mechanics and other Difficult Subjects

Conventionally, an understanding of the complexities of fluid dynamics has not been required to consider – and understand – their effects. Internal combustion engines are essentially air pumps, limited by the fact that they can only burn as much fuel in an engine cylinder as there is air in that cylinder. Its central design tenet is to create a marriage of all the oxygen with all the fuel in the very short time available, and to extract the work before it dissipates – or has to be dissipated – as unuseable heat. A core principle of design is that this is something the K6 will do in a manner never seen before; the design team was shocked to almost disbelief by the initial thermodynamic results. That led directly to the involvement of the University of Birmingham, and the resulting research indicated a series of unprecedented characteristics of the engine motions.

The design implications of these results were profound. Before the first drawing was set up in CAD, the likely thermal performance of the engine suggested that the need for any sort of independent cooling system might be avoided. It was theoretically possible to use the charge air as coolant, if needed, and that understanding drove much of the development process. Cooling as a concept was thus parked as potentially redundant. It has remained so throughout the design process to date.

The K6 as developed mechanically demonstrates a number of key features, all of which suggest that it has potential to deliver far better performance and economy than any other current unit. These can be summarised as follows:

- A radically different fuel/air mixing process and ignition/combustion
- A dramatically reduced engine phase angle occupied by the hot cycle
- The existence of high torque - the ability to do work – immediately after TC
- Default inlet and exhaust ports of 100% of the cylinder section
- A separate piston-ported scavenge port with independent timing
- Single inlet and exhaust fluid flows – no manifolds

The following subsections treat with these key features in the order listed above.

5.3.1 Combustion

The bathtub-shaped combustion chamber was quite a late-comer in the K6 design, but its development stemmed from a research analysis of what goes on in a CI combustion chamber. This suggested that the initiation of combustion in conventional engines was being slowed by the progressive injection of fuel, as latent heat was supplied for evaporation; this process kept the fuel/air mixture at the boundary layer between mixed and unmixed charge below the ignition point for some considerable time. When combustion did start, it was all over the boundary layer at once, producing the classic detonation, and the ‘knock’ characteristic of diesel engines.

In the K6 this simply does not occur. The fuel injector sweeps the combustion chamber end to end, so the first micro-droplet is not cooled by the second micro-droplet as it evaporates. Fuel reaches its ignition point virtually instantaneously, creating a flame wave which follows the injector path. Crucially, a single detonation event is absent from this process. This hypothesis, based upon extant knowledge, was confirmed at the UoB (Mason, 2018), albeit with a conical spray injector rather than the ideal flat spray, and some difficulties with the industry standard software.

The absence of a delay period and a detonation means that any fluid fuel can be burnt at c800K initial temperature, an initial temperature currently reserved for ignition-specific 'diesels'.

5.3.2 Hot Cycle

The motion of the K6, and its effect upon the engine hot cycle, was the chief determinant in the choice of the C:S ratio of 0.55. At this ratio, the engine motion to and from top-centre (TC) is concentrated (when compared to a sinusoidal motion) close to TC itself; 82.6% of the engine stroke is between 270/0 and 0/90 ATC (After Top Centre). There is very little slowing of the relative cylinder/piston motion around TC (the angular speed of the piston is at a maximum at TC). The compression curve from 270 to 0 is such that the pressure and temperature rise occur very close to TC, and are far from complete at 330ATC, as is the case in conventional engines. Compression heat losses are low and temperature high, a feature reflected in the absence of a dip in combustion chamber temperature as fuel injection starts. By the time significant fuel is in and evaporating, heat is being supplied by combustion.

After TC, as the work is being done, two other factors make a significant impact on the combustion process.

Firstly, since there is no detonation, there is no massive pressure rise in the cylinder. Secondly, as combustion proceeds the piston descends and work is done: torque achieves a maximum immediately after TC. The conversion of chemical energy to heat to work is coincident, not sequential. Cylinder pressure remains fairly constant, while working fluid temperature rises to reflect the volume change. When combustion is complete, both pressure and temperature drop, the latter having reached a local peak of 2400K, and an average throughout the cylinder of 1500K (after Mason).

The work done by the engine, coincident with the burning of the fuel, concludes at 1.1 expansions with pressure at c21bar. To the point of release, the total number of expansions is 3.88, with pressure c2.8bar at release, temperature c400K, IMEP c7bar (after Mason, UoB, 2018). This suggests charge air pressure and initial power pressure at 5deg ATC could be raised and fuel injection continue beyond the16deg ATC of the research project parameters (31deg injection angle available with one injector) with some effect upon efficiency but with significant additional power. Total duration of the hot phase (c400K+) is 100deg of rotation (350 to 90deg ATC). The combustion temperature remains at 800K+ for the first 50deg of rotation.

It is this short duration of the hot cycle, and in particular the period at which temperatures are above that sustainable by conventional materials (c750K for most applicable iron-carbon alloys), that prompted the discarding of any cooling system. It is one of the objectives of the prototype to run the K6 at the limit temperature of the materials – by use of insulation if necessary – to determine the effect upon the engine's thermal efficiency.

5.3.3 High Torque

In any engine driving through a crankshaft, the necessary time-displacement of the burning of the fuel and the execution of work is caused by the absence of crank angle near TC, and thus of any significant torque. The K6 rotary engine drives through the piston skirt into the cylinder wall, and as a consequence of this, maximum leverage ('crank angle' is not an appropriate term) occurs immediately after TC and is equal in the K6 to 106% of the piston stroke. At this key juncture the rate of piston travel is twice that of a conventional engine (mm/deg of rotation), so work can be done as the fuel is burnt. The length of that 'crank' lever diminishes as the stroke advances, but is compensated for by an increase in the angle generated between the conrod and the piston axle. Torque is thus both high – typically four times that of a conventional reciprocating engine – and evenly distributed over a large angle of approximately 90 degrees of rotation.

As the piston is also slowing during the power stroke and its 'orbit' is changing relative to the main mass of the engine (the rotor), so also is the piston dumping the energy of its motion into the rotor, raising the engine output. This process is reversed during the compression phase, where the rotor sheds energy into the piston to drive it to TC.

5.3.4 Big Ports & Separate Scavenge Port

Current engines typically have four poppet valves mounted on one end of the cylinder, giving about 25% of the bore area to exhaust and 40% to inlet. This feature was first used some 80 years ago and has not been superseded. The pipes serving those mushroom valves have at least one 90deg turn (to avoid the valve stem), and are bi-, tri-, and quadri-furcated as fluid flow systems. They are opened and closed by cams that are limited by the angle they work at and the acceleration they can provide to the valve itself. From a design standpoint this is a limitation, yet these systems have been made to work through the century and more of the development of the IC engine.

Such limitations do not exist in the K6: the exhaust port is simply a hole in the stator. It opens to 100% of the cylinder section and is precisely aligned to it. It has no mushroom plate in front of the hole, no stem in the hole, no 90deg bend to spin the gases. The inlet port is the same. Both open and close in, quite literally, the blink of an eye.

The key events are outlined in the table below:

Degrees ATC	Event
0 – 5	Fuel injection/ignition
90	Exhaust commences opening
100	Scavenge ports commence opening
106	Exhaust port section 50%
118	Scavenge ports 50% open
130 –140	Exhaust port 100% open
130	Scavenge ports 80% open
152	Charge air port commences opening
172	Charge air port 50% open
180	Exhaust port closes, scavenge ports 100% open
192 – 230	Charge air port 100% open
220	Scavenge ports 80% open
252	Scavenge ports 50% open
254	Charge port 50% closed
270	Charge and scavenge ports close

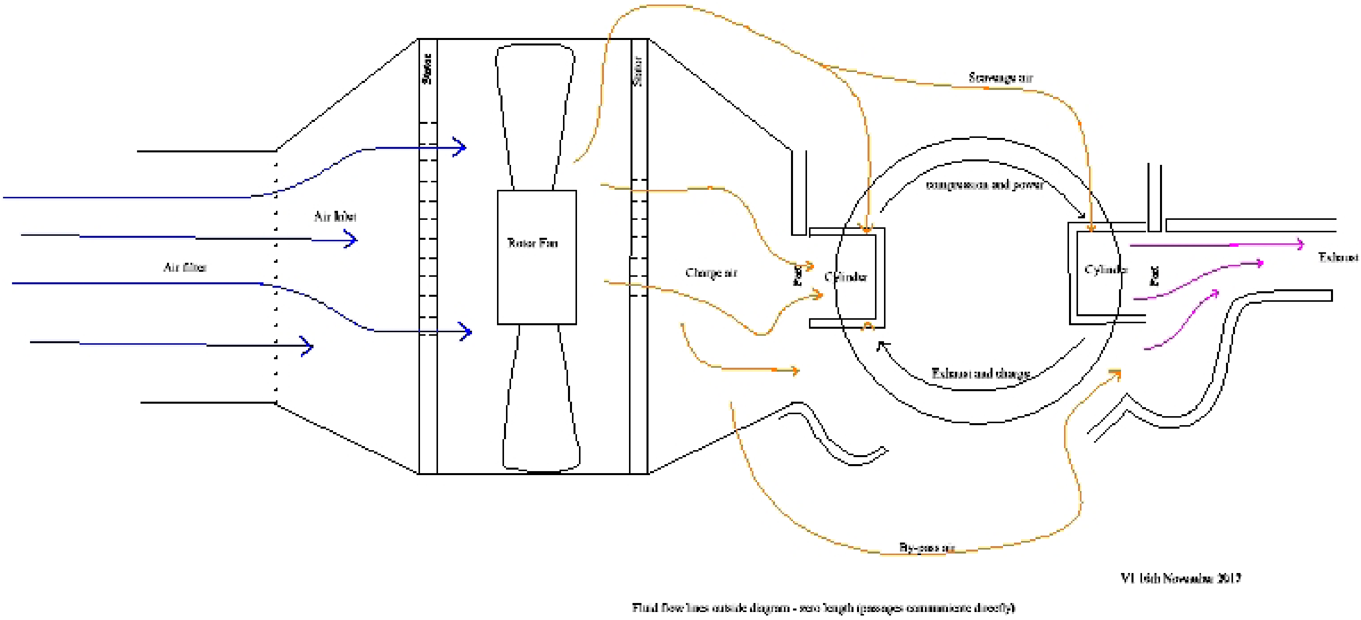

Fig. 3: Fluid flow schematic for the K6 engine

As can be seen, a separate scavenge port introduces fresh charge air into the base of the cylinder as soon as pressure drops below inlet pressure during the exhaust phase. To change these inlet and exhaust events it is simply a matter of changing the hole sizes and locations in the stator.

5.3.5 Pumping Air: Engine External Fluid Flows

As a two-stroke unit, the K6 does not rely upon the positive scavenge and extra motion of the Otto cycle to give fluid flows into and out of the cylinder, but relies upon two features. Firstly, the rotor is an inlet turbine providing air at pressures above 1bar at the scavenge and inlet ports. Second, the energy in the exhaust gas pulse creates vacuum in the exhaust and thus a pressure difference between the two sides of the engine.

The K6 is designed on the basis that it will extract sufficient energy out of the working fluid as to render an exhaust gas turbocharger both redundant and inapplicable at this stage.

The stator frameplates, the outer edge of the stator, and the engine casing, are formed to provide two compartments for air handling. Fresh charge air is drawn in on one side, passes into the rotor to be compressed, and emerges to feed the scavenge ports and the charge port. The engine casing is thus at inlet air temperature, and the charge air passes over the face of the stator, where it can act as coolant if required. The charge air passes through and around the stator and cylinder. One of the unknowns at present is the need for insulation on the compression and power sectors of the stator, and the outside of the cylinder.

5.3.6 Sundries: Limited by the Simplicity of Design

The simplicity of the K6 was the prime reason for the project at conception; its potential in other aspects emerged as design proceeded. Only three key components are new: the rotor, the piston axle support system, and the stator. The few other components are either off-the-shelf bearings and bolts, or adaptations, usually simplified, of existing components. The piston is one exception; its length and compartmentation are dictated by its dual function as combustion chamber and driveline through the skirt. It also contains lubrication passages, there being no loose oil in the cylinder, coupled with the need to supply oil at pressure to the engine drive output faces (piston skirt and cylinder wall).

The short engine component list, working outwards (numbers in brackets if more than one), is as follows:

Piston Axle	Piston axle support (2)
Conrod (pair – fork and blade type)	Gudgeon Pin (2)
Piston inc rings (2)	Cylinder liner (2)
Rotor	Stator
Rotor/stator/piston axle bearings (6)	Bearing housings (4)
Exhaust pipe	Stator frame plates (2)
Airway separation plates (2)	Air filter housing and filter
Oil Tank and feed pipe	Engine casing
Piston axle torque bracket (2)	Output drive ring
Output shaft	Assembly bolts (c10)

6. Business Case

6.1 Costs

Completion of design		
Senior engineer 1 year FTE @ £50K + 100% o/heads		100,000
Junior engineer 1Year FTE @ £35K + 100%		70,000
Project manager 0.2 year FTE @ £50K + 100%		20,000
Manufacture		
Patterns, moulds etc		25,000
Casting and machining, inc materials	(say ten sets)	100,000
NDT components		10,000
Assembly		20,000
Injector - new type – say		50,000
Testing		
Laboratory costs		70,000
Senior engineer as above		100,000
Junior engineer, do.		70,000
Consultancy costs		
David Gibson 1day/week @ £300/day, 2 years, say		32,000
Owen Jordan, do.		32,000
Travel and expenses, say		6,000
		705,000
Risk		
25% of sub-total, say, for unforeseen items		195,000
Anticipated project out-turn		£0.9m

6.2 Timescale

Framework agreement	Jan 2020
Design Commencement	Feb 2020
Component production start	May 2020
Design completion	Feb 2021
Component production complete	April 2021
Assembly	May 2021
Testing commencement	June 2021
Testing completion	June 2022
Production of units for sale	Autumn 2022

6.3 Markets

6.3.1 Micro-CHP

The initial area identified for scale production is micro-CHP in the domestic boiler replacement market. Here, the current price of gas is c4p/kWh delivered. This compares with c19p/kWh for domestic electricity supply. For such a market a single phase AC alternator could be mounted directly upon the rotor and any drive take-off eliminated, the alternator being arranged to act also as a motor for starting. Charge air would cool both engine and generator, and the exhaust would lead to a conventional heat exchanger and condenser. This would be fitted with an electric heating element driven off the alternator to balance the supply and demands for heat/electricity.

On a 50% thermal efficiency (to generation) basis, a micro-CHP unit would, under current market arrangements, cut the domestic consumers energy bill for electricty to about 8p/kWh when the micro-CHP unit was supplying energy for electrical generation only, a saving of nearly 60%. Hot water supply only at the same rate would suggest that hot water would, de facto, become free at the point of use if coupled with conventional storage systems (to cover the time-displacement of the need for electricty and hot water). Heating during the winter months, would probably also be de facto free at the point of use; if the Micro-CHP unit were optimised for generation of electricity, the thermal mass of the property would work as a suitable store to balance heat supply and demand.

Consumers would face only one bill, for gas supplied, and would see their energy bills fall by perhaps 50% in total.

Adjustments to the generation rules, to permit Micro-CHP unit owners to supply (and be paid for) energy to the 'grid', would optimise this system and permit full utilisation of Micro-CHP units as base generating capacity. This would almost certainly prompt the generating industry in some countries (esp the USA) to offer subsidies to installers on the basis that it would be cheaper than building new central plant. On that basis, any over-cost of a micro-CHP unit to the domestic customer, over and above a current replacement unit, might well be avoided by such an arrangement.

This market in the UK is conservatively estimated at 1.5m replacement boilers per annum; a market worth perhaps £4bn per annum. Worldwide, this market is at least 10x that in the UK.

6.3.2 Commercial/Industrial CHP

Commercial users typically use boilers of 30kW to 1MW or more (a typical UK primary school, for example, has a single 750kW boiler, secondary school 2 x 1MW). Electricity demand is typically more than heating/hot water demand; in offices and shops, lighting and other power loads will exceed heat demand for all but the warm-up phase after the optimum start system kicks in in the morning. Much of that load is in air conditioning when the building is at temperature. The balancing of heat/electric demand is thus much more varied, and many sites will have significant solar PV systems as well.

The potential for both commercial and industrial users to move to self-generation is thus huge, and CHP units in this range are obviously economical on gas in view of the price differential; any site with space or process heating requirements could easily justify a change, even if not all of the 'waste' heat could be utilised all of the time. Ultimately, the limits of the thermal efficiency of the K6 will determine the extent of market penetration, which will obviously be lower where oil is the fuel, and higher where renewables or process waste can be utilised at low or zero nett cost; the K6 can readily be modified to steam power.

6.3.3 Transport

Automotive is currently the largest world market for reciprocating IC engines, both SI and CI format, and most units are in the 50kW to 0.5MW range. However, the motor vehicle is designed around the reciprocating IC engine, as has been the case for at least twelve decades; the design of one has dictated the design of the other, not least on issues of size, weight, power, noise and the need for repair and servicing. On all of these fronts the K6 as an engine has no features that are even remotely comparable beyond its power output.

The automotive industry is also conservative; it is intensely competitive on its own terms, but equally has not suffered any external competition for the whole of its existence. The presumption is that there is a market for motor vehicles, and that offering more value – however that concept is interpreted – than your competitors, will sell the product. Market penetration of the K6 into this closed sphere is thus anticipated to be a very difficult proposition; a small aircraft carry-on bag housing the engine that can fit between a pair of seats and be neither seen nor heard is outside the industry comfort zone.

An engine that costs very little compared to existing units, needs a fraction of the manufacturing resources, yet demands a complete re-write of the industry over-view, is a proposition that is difficult to see the future for. Take-over could be completed in five years, or it might take a mite longer...

Commercial vehicles, especially the larger units where volume and weight are an issue, and where engines take up volume and weight that could be used for goods, are another matter. Here a 400kW unit the size of a suitcase is likely to take the market almost straight away with reduced costs, servicing and fuel requirements to add to greater payloads.

Much the same can be said for peripheral transport such as rail and bus, where commercial road units double up as power on a wide range of public service vehicles. Market penetration will be much slower, since fuel and other engine-associated costs are but a small portion of the cost of running these vehicles. Reduced emissions and the ability to burn renewables might tip the balance here, where in commercial fleets it will be of lesser importance.

Rail's reliance on larger power units of the 1-5MW size is dominated by the reciprocating diesel on the commercial railroads, and the 25kV mains-fed electric units on the passenger systems. In the former market there are really only two suppliers: General Motors, who have dominated the market since the 1930s using essentially the same engine, and General Electric, who have been effective competitors during the past four decades. Again, the K6 is a potential market winner in both sectors, not least because the thermal efficiency of the electric railway is very low. Again, too, the conservatism of the industry is very great, even more than automotive, and that may affect timing of the takeover, but not ultimately the fact of it.

Second only to automotive in the transport field, however, is aircraft. This is very high on the political agenda, since the thermal efficiency of the gas turbine is low, and alternatives currently absent. Matching the USA level of use of internal passenger flights across the globe – as is slowly but surely happening – would mean a many-fold increase in emissions. Substitution of the gas turbine by the K6 would do much to alleviate the implications of that expansion in terms of thermal efficiency, noise footprints, emissions and the application of renewables. Again, a complete re-design of the commercial jet aircraft would be required, but in this case there are already the design resources in place, concentrated in a handful of manufacturers who are only too aware of the need to create serious change within their industry on these fronts.

Market penetration into the air industry is thus deemed do-able in view of the low cost, wider benefits, and the simplicity of the K6 compared with the gas turbine.

A very similar conclusion can be reached for the international shipping industry, where very large reciprocating units take up space and make considerable noise and emissions impacts.

6.3.4 Portable power

Entry level (c1kW+) revolves around battery powered electric units. In commerce, industry, construction and civils, the CI unit predominates. Market entry is relatively low cost at the low power end: the most likely area for market penetration. The market is huge; from hand-held garden tools to portable generators and construction equipment.

6.4 Marketing Costs

What investors will need to spend to get the K6 installed as the power unit in the market of their choice will vary tremendously. Domestic micro-CHP units could be as little as perhaps £2-5m, rising in automotive to £100m. Within the aircraft industry, a price tag of £1bn to design and make a new K6 friendly airframe might well reserve this market for large consortia with considerable ability to absorb financial risk.

6.5 Conclusion

Finding the right market, and the right entry point in that market, is a challenge that cannot be underestimated. The cost might be as low as a few tens of thousands, but such speculation is beyond the scope of this document as the risks are unquantifiable here. Given the low development costs of the K6, it is appreciated that equally low retrofit costs to existing designs might get the project the required level of momentum very quickly indeed.

The prototype will show what the engine can do; it will not show it doing it. However, such a step is beyond the current phase of the project, which presently offers low costs and risks. In terms of some industry players it would barely constitute a hurdle at all in the cost department, and that in turn carries its own set of risks. In terms of breaking moulds, there are some industries – automotive being the prime case here – where engine costs are so high that they are shared between competitors. Current investment in plant is so high as to cause anyone to think twice before going for a unit whose design is sufficiently simple that it could be built in a garden shed.

7. Prototype Specification

Basic design parameters. All dimensions in mm unless otherwise identified.

Bore & Stroke : 102 x 80

Conrod: Stroke ratio : 0.55

Stroke completed @ 90deg ATC, % : 82.6

Combustion chamber: In piston crown, bathtub shape

Rotor body, pistons, conrods and stator: Iron:carbon alloys

Rotor/stator seal: labyrinth

Lubrication: single gallery in piston axle, oilways; total loss

Piston reaction forces: piston axle mounted in stator casing

Cooling: charge air

Torque arm length @ TC : 106, @90 ATC :68

Clearance Piston to Stator @ TC : 1mm (as combustion secondary air reservoir)

Rotor diameter : 300mm

Power take-off: drive ring on rotor to output shaft

Conrods: 44 between centres, fork and blade type

Fuel: diesel

Compression ratio: 17:1

Nominal swept volume: 653cc per piston stroke (1306cc total/rev for both ends of cylinder)

Number of cylinders: 1, Cycle: 2 stroke (one power stroke per piston, total 2per revolution)

Scavenging: Piston ports

Exhaust commences: 90deg ATC

Inlet port closes: 270 deg ATC

Compression phase: 82.6% of stroke

8. Notes

The K6 is intended to be a prototype that demonstrates the principles of this type of rotary engine. It is not intended in any way to be a fully developed market-ready unit for any particular purpose. Neither does it pretend that it represents the sum total of development by the design team; its scope is simply to prove the basic design and provide a testbed for analysis to outline pathways for future research and development on the design and concept.

At various points in the design process the staff and students at the University of Birmingham and the University of Santa Catarina, have made suggestions that have contributed – directly or indirectly – to the prototype specification. The prototype is thus a reflection of those inputs, and the design team recognise their efforts whilst not being able to immediately credit their work to any particular point of the design. Prof. Miroslaw, for example, made comments about the air handling at an early stage, and much of the prototype charge air design reflects work done as a consequence of those comments. Those comments were however solely verbal, and were on points of principle, not detail design.

In respect of the key design aspects of the K6, it can be fairly stated that, to date, where claims, such as the elimination of the delay period in combustion, have been made, work by the two universities has confirmed the initial hypotheses.

It has also become clear to the design team that the scope of potential development of this kind of rotary-reciprocating engine, which eliminates many of the drawbacks of current CI and SI units, is far wider than just matters of size, output, thermal efficiency and markets. The vast range of engine motions to be derived from the conrod:stroke ratios has been barely touched in the design of the K6. The potential of the Siemens 'differential' piston axle to rotor gearing, for example, is acknowledged but unexplored; it was a failure in its original application for reasons that had nothing to do with the gear itself. Its potential is however latent. This is by no means the only unexplored aspect of the K6-type.

Finally, the K6 design team acknowledge that their skills and interests in the initial stages of the project, were not focussed upon the IC engine per se; the design was a spin-off from the York steam engine project that simply begged to be developed. That the team did in fact do so was more a consequence of the obvious worth of the K6 than the team's initial abilities to deal with the issues the design raised. The University of Birmingham in fact has done a considerable amount of work on a steam version of the K6, and that also continues. The issue of portable power in the 21st century is one where, at present, the world's industry and research remains focused on a narrow region of technology – a region that has its own substantial and inherent set of problems. The K6 has been developed with that in view, and with the knowledge that dominant technologies are never easy to change.

- Owen Jordan, 10th September 2019

9. Personnel

Owen Jordan

Has led the design of the K6 following its spin-off from Winnings Trains. With no formal engineering training, but a lifetime of experience in design, building services engineering and as a consultant and project manager, he has had to learn much of the theory underpinning the K6 from scratch. Undergraduate and postgraduate students asking difficult questions proved excellent spurs to the acquisition of knowledge.

Educated at Hessle High School, Hull College of Technology and the University of Wales, he had a decade in local government and a second decade in private practice before becoming a consultant in 2000. Married to the same lady for forty two years, with two grown-up sons and one grandson, he now runs a small property business, and keeps his hand in on his professional roles, whilst pursuing a wide range of non-profit making interests. He lives on the side of a mountain in South Wales.

David Gibson

David has a wide skillset which includes Project Management, Strategic Advice and Troubleshooting. He is also an innovator, most notably responsible for the RAILFAST Project (RAIL Freight using Automated Sorting in Transit). Regarding the K6 rotary engine project, David is Project Coordinator with duties which include Academic Liaison. His role has includes 'holding the vision' and helping others to stay true to that vision.

David's current clients and partners include: Jordans Consultancy, Sort-IT.Biz, TruckTrain Developments and Danvers International. Aside from the K6, his current live projects include: Intelligent, integrated, high-speed rail freight (RAILFAST), 2nd Generation Rail and self-contained palletised chilled and frozen freight (Box3). He has served as a Trustee for the Atlow Mill Centre for Emotional Education.

Having a strong background in IT, Transport and Logistics, David was educated at St. Anne's School, Fareham before moving on to Fareham Technical College. He holds a BSc. (Hons.) Degree in Electronic Engineering & Physics from the University of Technology, Loughborough. Prior to going freelance in 1997, David was employed in various IT-related roles for both GPT Limited and OKI Systems (UK) Limited.

In his spare time, David enjoys walking, creative writing and working in support of animal-related causes.