The SES Steam Car and Engine-A Brief History

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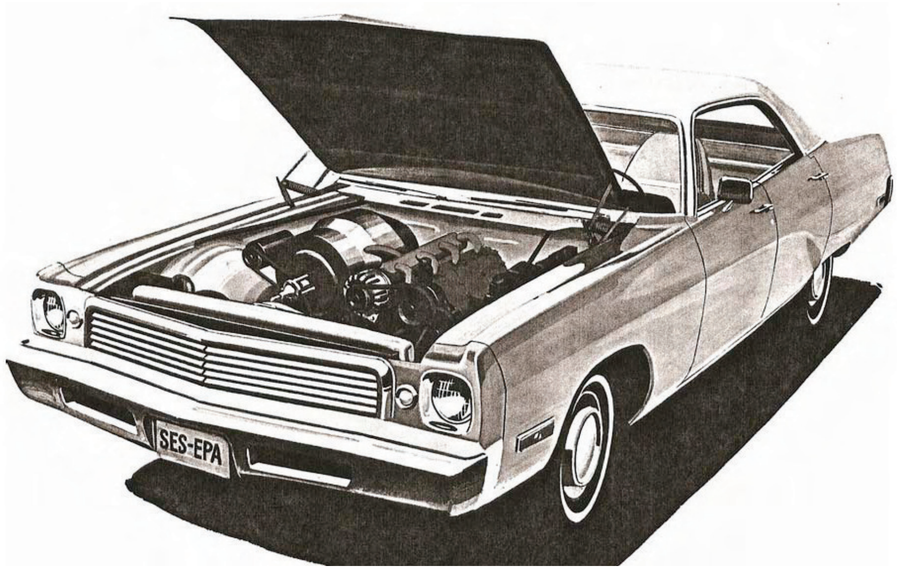

Fig 1: An artist's rendition of the Plymouth Fury with the final under-hood arrangement.

The Project

In the early 1970s, SES Corporation of Newton, Massachusetts, won a contract to build a steam engine car demonstrating non-polluting car engines in the United States. SES (initially an abbreviation for Steam Engine Systems, later for Scientific Energy Systems) had built several prototype steam power plants by that time, the expanders being a conversion of a compressor or a diesel, the feed pumps being off-the-shelf industrial types, etc. This time SES designed its own boilers and burners from the beginning, gaining experience while achieving the desired low-polluting combustion and, with it, patent protection. The car project was funded and directed initially by the federal Environmental Pollution Authority and later by the Department of Energy.

This history focuses on the steam engine installed in a 1974 Plymouth Fury and tested on a chassis dynamometer.

The working fluid was water, the fuel gasoline. The boiler containing the burner in its center was compact enough to fit next to the expander under the hood. The only modification to the Plymouth *Fig. 1* consisted of enlarging the radiator space to house the inevitably huge condenser and fans necessary for the fully closed system. The condenser area was such that the ram air alone sufficed to cool at cruising speeds and average air temperature. The condenser fans were operated hydraulically to enable matching their speed to the demand thus minimizing the otherwise substantial power drain inherent with closed-loop steam cars.

The Expander

The expander configuration *Fig. 2, Fig. 3* was decided upon weighing the many criteria inherent in the passenger vehicle application. The engine was an in-line, 4-cylinder, single-acting uniflow with trunk pistons and runs oil in the crankcase. This configuration was chosen after investigating many other schemes. Steam admission was cut-off controlled, the mechanism consisting of two poppet valves in series; steam would enter the cylinder when both valves were opened. The valves were operated by two camshafts, and the variable admission was accomplished by phasing one camshaft against the other via a hydraulic mechanism, its position controlled by the accelerator pedal.

All the controls were fully automatic; the driver needed only to "turn on the key" and in about 20 seconds the car was ready to move, the expander idling and capable of driving all the auxiliaries and accessories (including air conditioning. Was this the first air-conditioned steam car ever?). An automatic transmission enabled the familiar P R N D selection. About 45 seconds were needed to have the full power available at the wheels.

It is a common knowledge with steam engines that the steam consumption and the resulting fuel economy, is a function of both steam pressure and temperature. While the high pressure gain diminishes beyond a certain limit, the temperature increase is theoretically beneficial to no end. The SES system was designed to the

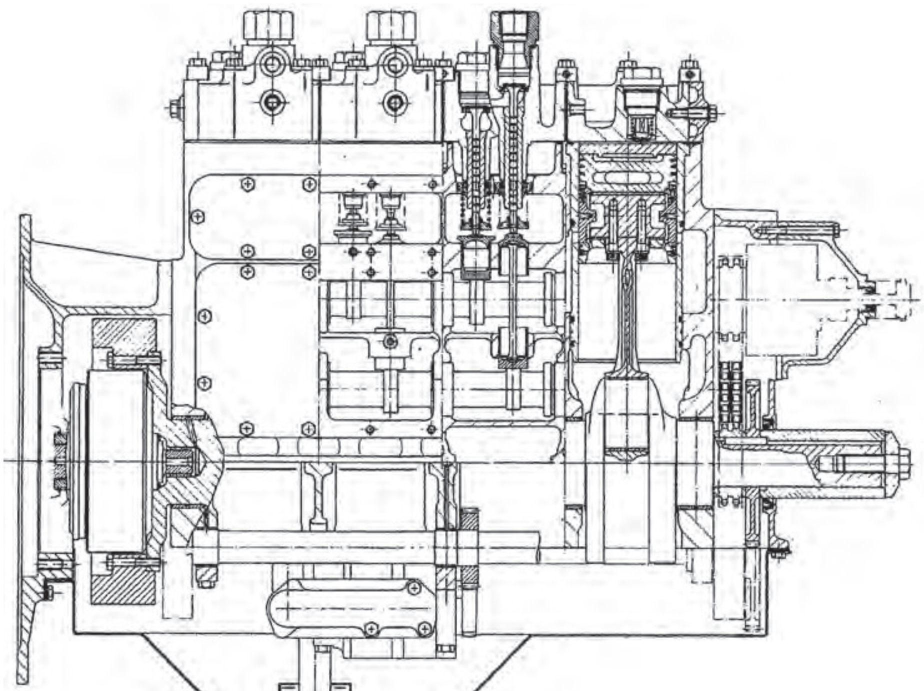

Fig 3 The L-4 prototype expander in longitudinal cross section. The step-up gear assembly, shown in the flywheel on this picture, was eliminated in the final version.

practical limit of both parameters, settling eventually on delivering steam at 1000 psi and 1000 ºF to the expander inlet at all times. Special lubricants with additives, and materials for the cylinder liners and piston rings, were developed with the help of subcontractors, such as Exxon, to handle the high temperature in the presence of steam.

Employing the trunk piston rather than a crosshead design, to save space and mass, necessitated oil/water separation. The crankcase water separator was neatly incorporated in the camshaft phase change mechanism thus taking no extra space or adding mass. The cover of the mechanism is visible at the “nose” of the expander, above the belt pulley. As luck would have it, exhaust steam/oil separator proved unnecessary (imagine the size of it!) as the condenser effectiveness was not impaired by any of the oils tried. An oil/water separator would reclaim the oil from the liquid stage. Nor did the boiler mind somewhat oily water – there never were any deposits in it, even with gross over-oiling, probably because of the high velocity of the minimal water inventory in circulation.

Engine Size

The power needed for the EPA-specified car load, max speed, and acceleration led to the need for about 100 kW output, and that scaled the size of the components. For the expander, 89 mm bore and stroke proved ample. Ample meaning that it turned out rather oversized for the automotive duty as was concluded a couple of years later. See the table at the end. It could deliver more power than needed at the rated 2500 rpm. It could also run much faster quite happily as was noticed just after the output shaft sheared at full power.

Series Poppet Valves

The in-series scheme of the two poppet valves offered two possible arrangements: the cut-off could be closed by the valve closer to the cylinder or vice versa. The difference mattered in handling the discharge of the steam trapped between the two valves. Initially, a less efficient arrangement was selected where the volume of steam between the two valves did not discharge into the cylinder. It was felt that even at zero cut-off, that this small volume of steam would still deliver too much power at idle. Tests revealed that the parasitic losses in the actual car required more power than this provided, and so a reverse arrangement that would result in better efficiency was happily instituted during the later stages.

Drive Line Concerns

To limit the vibration caused by the reciprocating masses, a counterbalance shaft was positioned in the crankcase. To increase the rpm of the output shaft and lower the maximum torque delivered to the drive-train, a planetary gear set was incorporated into the flywheel. To lower that pulsation and vibration on the drive train, a torque fluctuation damper was placed at the flywheel. These devices did a good job of speeding up and isolating the drive train, but unfortunately they themselves could not take it. In a bold move, both were eliminated in the final version when it was found that the car drive train itself was torsionally “soft” enough to withstand the torque fluctuations. A change in the rear axle and the transmission gear ratios took care of the loss of rpm, and the step-up gear was relegated to the bin of unnecessary precautions.

The reader may well wonder why there was a transmission used in a steam engine in the first place. The gear change was necessary to meet the acceleration and the max speed spec. That spec reflected the muscle-cars era mentality. Remember the rubber burners? As torquey as every steam engine is known to be, it still lacks power at low rpm. And in any case, a direct drive was impractical with the accessories and auxiliaries that were to run all the time, nor was it feasible to squeeze in an auxiliary engine for that function let alone struggle with the resulting complexity of two power plants. A stock automatic transmission was a proven solution, and was also cheap since Chrysler Corp. was a subcontractor.

Fuel and Burner Design

The fuel specified for the car was to be the ordinary, no-lead gasoline. The burner and boiler were developed as one unit that would provide a combustion chamber shape suitable for the homogenous gasoline-air mixture to be burned with near zero pollution. See *Fig. 4*. The burner fan was hydraulically driven, air and fuel flow both controlled independently to match the power demand and the low emissions demand. The turn-down ratio was 20 to 1, and the “throttle” response, to use the IC engine terminology, exhibited no appreciable lag going from idle to full power. This boiler with its burner was described in the *Bulletin* several years ago.

As said, water flow, gasoline flow, air flow, temperature and pressure were all automatically adjusted without driver’s input other than the movement of the accelerator pedal. An in-house developed feed pump was directly driven from the expander and could deliver zero to max flow at any speed without by-passing. It had solenoid-controlled inlet valves, one with each of its three plungers. A power input minimizing arrangement, this feature also al-

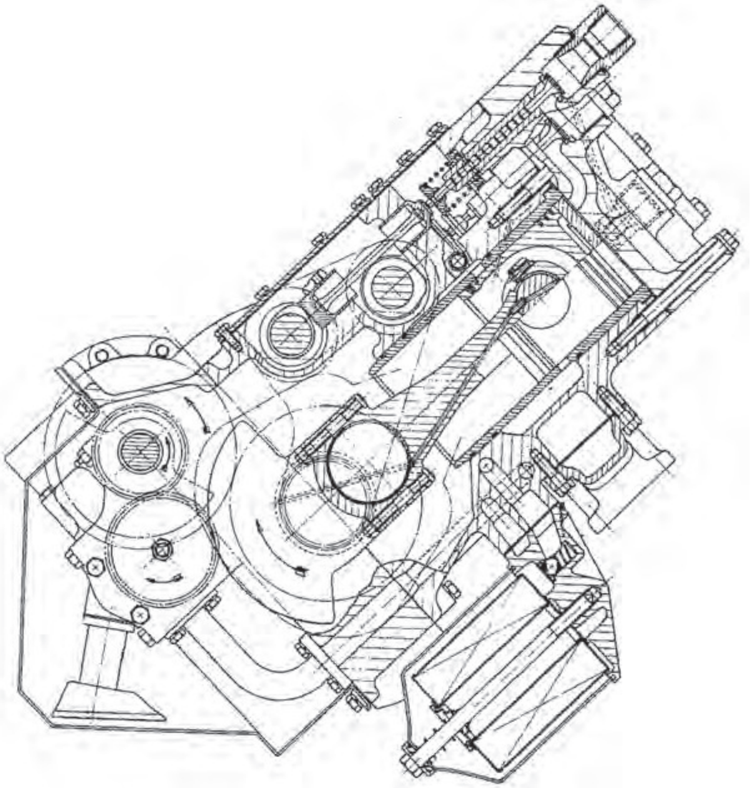

Fig. 2 The L-4 prototype expander shown in transverse cross section.