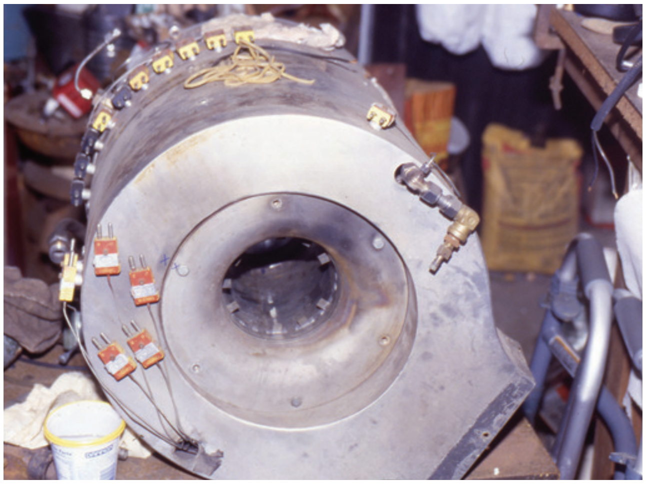


lowed drainage for freeze protection. The instantaneous zero-to-full flow was a nice feature as, with the monotube boiler having essentially no water reserve, the controls proved a nightmare when trying to get everything adjusted right and fast. The electronic control assemblage took up the trunk space in those pre-computer days. Most components were standard laboratory control modules, since the development of dedicated controls was not within the scope of work.

The Performance Map

In the final stages of the program a complete performance map of the power plant was drawn, calculated from the measured data. See *Fig 5*. It has not been published before because, as often happens, projects die without much trace when funds run out and interest wanes. The years past the 1973 oil embargo were not favorable for funding steam cars. The term "mpg" came into frequent use. The mpg of this huge car was respectable but still a thorn in the DOE image. After the car was tested, demonstrating that it met the specs, then the funds were directed to fuel economy improvements, a program that encompassed every aspect of the power-plant and drive train including auxiliaries and accessories. The performance map is presented here for posterity and therefore it is in SI units to be easy to use by the next generation of steam nuts when the time comes again to revitalize steam engines for transportation. The DOE overseers also required the use of SI metric units.

The map allows predicting the performance of reciprocating steam plants of a wide range of sizes and power as long as the expander is of a similar configuration and the steam pressure and temperature are similar. Interestingly, temperature had little effect on performance in the range above some 750 ºF. Certainly, SES could have saved itself lots of headaches had it known this from the beginning, because lowering the temperature while receiving the same performance would have eliminated much of that expensive research into exotic lubricants and wear properties. Lower temperature would have also made the use of the finicky throttle valve easier, a valve that was hoped would not be necessary but in practice the fully automatic control was too difficult to achieve without it. It also turned out that, contrary to the results obtained on a dynamometer, overall efficiency did not suffer all that much, even improved for some operating regimes, at a lower pressure. Let these be lessons for posterity.

Hal Fuller towers over a boiler coil stack from his extensive steam accumulation.

In the chart axis, BMEP stands for Brake Mean Effective Pressure. It is a measure of what's commonly called "load" and it shows how hard each unit of volume of steam in the cylinder works, that is, how well the engine utilizes its displacement volume for producing power.

MPS stands for Mean Piston Speed, which is a parameter akin to rpm except that it is universal for all reciprocators. With the SES expander, as an example, 7 m/s is about 2400 rpm or 40 rps.

BSFC and BSEC stand for Brake Specific Fuel Consumption, and Brake Specific Energy Consumption, respectively. The BSFC is in grams of fuel per unit of work produced on the shaft (g/MJ); it is a measure of how much fuel is needed for a unit of that work. The BSEC is a measure of how much energy is needed for a unit of that work. It is a ratio of energy in fuel vs. the useful work (rather than the mass of fuel). Unlike the BSFC, BSEC is universal for any fuel, be it kerosene, propane, natu-

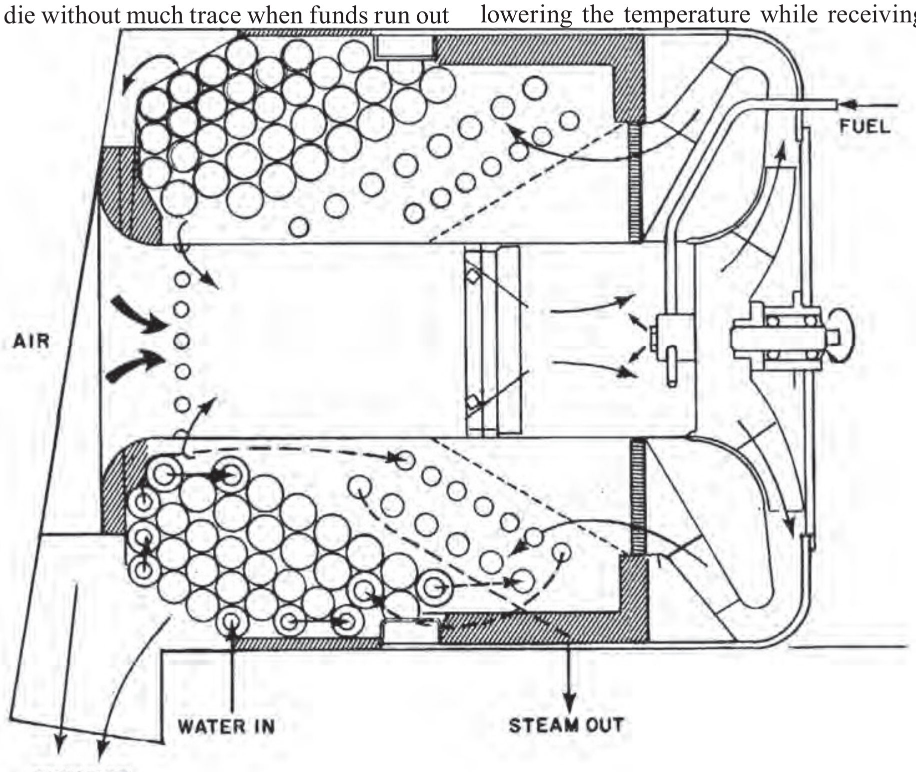
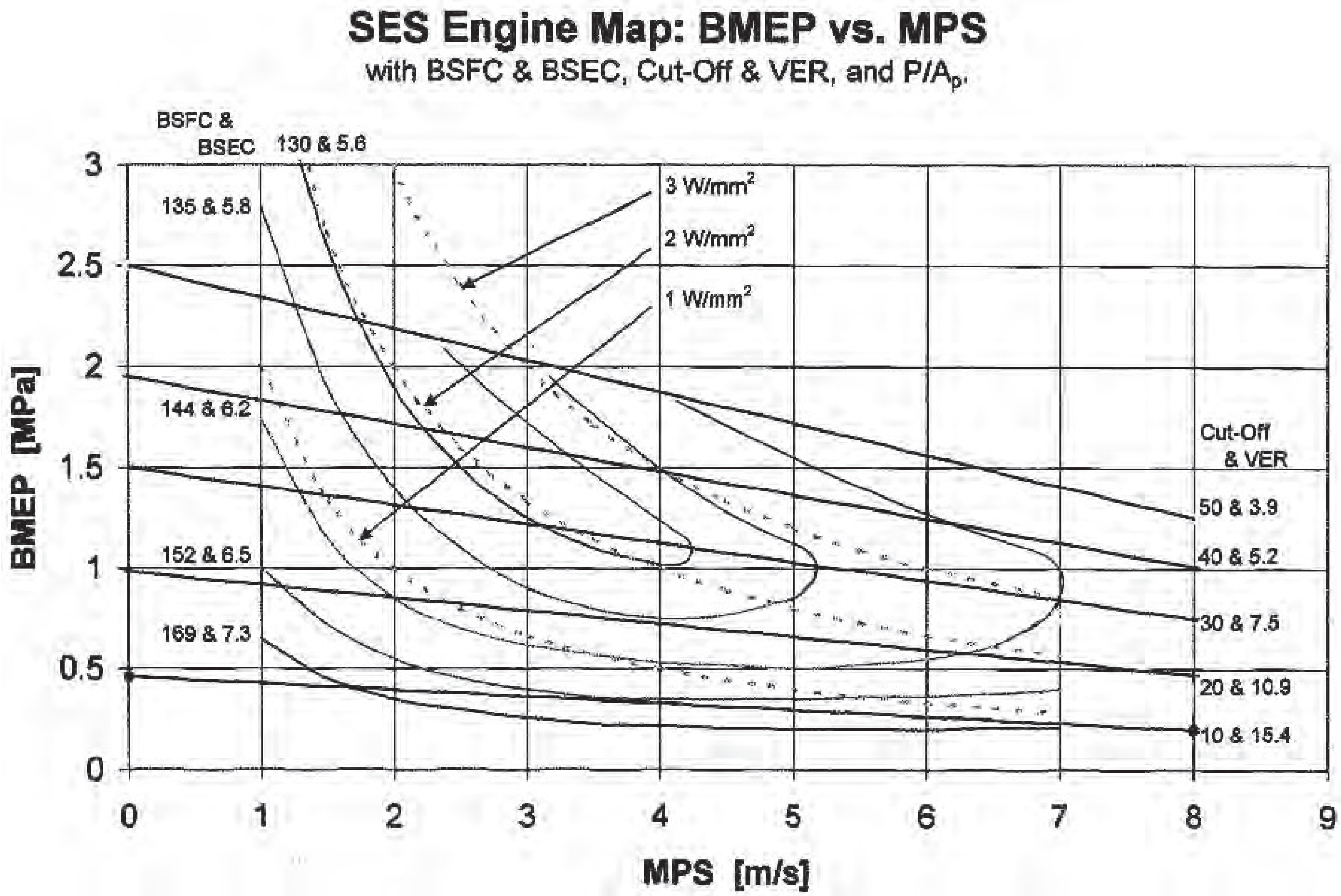


Fig. 4 The longitudinal cross section of the boiler/burner assembly.

Fig. 5.



ral gas, or gasoline. To figure out the mass flow all one needs to know is the specific heat content of the fuel in question (it is 44 kJ/g with gasoline).

Finally, the 1, 2, and 3 W/mm^2 lines (P/Ap) provide a measure of how much power one can expect from a unit of the piston area. It looks like about 2.2 W/mm^2 would be obtained in the best efficiency region.

On the right-hand side are the numbers for the Cut-Off and for the VER. The Cut-Off is in crankshaft degrees. The VER stands for Volumetric Expansion Ratio, the ratio of the total volume in the cylinder divided by the volume at the point of the inlet valve closing. It is akin to "percent cut-off" but it includes the impact of the clearance volume.

With this graph, one can estimate the performance of similar engines, as said. It shows that, for example, the best fuel efficiency corresponds to the speed between 2 to 4 MPS and VER of 7 to 4. This island of the high efficiency is quite broad indicating that efficiency was not all that sensitive to those parameters.

Lastly, readers might be interested in the heat balance of this engine. As with all car engines, this one would also run at partial load most of its life. The table in *Fig. 6* shows the distribution of power in kW and percent of fuel energy for three cruising speeds. A post 1973 spec might have focused more on low consumption at these conditions and that would have lead to a smaller and cheaper engine.

What happened to the car?

From SES it went to the Larz Anderson Museum that was located on the Boston waterfront at that time. A few years later the museum decided to relocate back to its previous location in Brookline, Massachusetts, where it had a substantial collection of antique cars, including several steamers. It did not want a modern car there, and agreed to store it at the National Steam Propulsion Co. in Woburn MA. When NSP was bought by the Skinner Engine Company of Erie PA, the car went there. Several years after it acquired the steam car Skinner closed for business and all inventories were auctioned off. Presently, the car is stored in an undisclosed location; plans are to include it in as yet-to-be announced museum.

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Portion of full power [%]	13		22		30	
	kW	%	kW	%	kW	%
LHV Input	97	100	122	100	165	100
Net Expander Output	11.9	11.8	19.8	15.3	26.7	16
Exhaust Steam Condensing	60	59.8	77.4	59.6	103	62
Boiler/Burner Stack Loss	6.6	6.5	8.9	6.8	12	7.0
Valve Stem Leakage	3.1	3.0	3.1	2.3	3.1	1.8
Crankcase Blow-by	3.2	3.1	3.2	2.4	3.2	1.9
Oil Cooler	3.5	3.5	4.6	3.5	5.5	3.3
Surfaces Cooling Loss	12.3	11.9	13.1	9.9	13.7	8.0
Error		0.4		2.6		0

Fig 6. The power-plant output and energy distribution at partial load. The table shows the heat input, mechanical power output, and losses at vehicle speeds of 40 mph, 50 mph and 60 mph.