Sound proof box enclosed Honda 2000 IU Generator under Load with a Marvair 16,000 BTU Marine Air Conditioner

The Sound Box

I wanted to use my Honda 2000 on my Catalina 375 sailboat to run its air conditioner, charge the house batteries, and make hot water but not all at the same time. The Honda 2000 has sufficient power to do these individual functions one at a time. The Honda 2000 is quiet but it is still too noisy for most people when running at full load sitting on your boat's swim platform or fore deck. I designed an enclosed sound proof box for the Honda which used a specially designed wet exhaust system to dampen the exhaust noise and direct the wet exhaust to outside the hull just above the water line.[1] The sound box was custom built into the starboard stern lazarette just above the diesel fuel tank, see attached picture. In addition to the wet exhaust cooling I installed two 3" inline blowers that were powered from the Honda 12V output plug. These blowers sucked hot air from the sound box out through the stern vents and to the open air.

The sound reduction was substantial producing the following sound tests. At anchor with no generator running the cockpit area showed general ambient background noise at 47db. Start the Honda, put under full A/C load, and leave the sound box lid off (Honda exposed to open air, with the meter next to the sound box) showed a reading of 68 db. Place the sound lid on the box and place the meter on the hatch lid, the reading was 53 db. Walk around the cockpit and the reading was 51-52 db. Sit out on the foredeck, and the reading was 48 db. Below decks in the salon with full A/C load the reading was 51 db, in the aft cabin 52 db and in the V-berth 49 db.

The factory rated sound of an open stock Honda at full load is 59 db at 9 feet distance. For every increase in 10 decibels, the noise level is 10 times more powerful. A generator that runs at 60 decibels is ten times as loud as a generator that runs at 50 decibels.

[1] Exhaust back pressure to the Honda (using the wet exhaust system) increased by only 9% over a standard air cooled Honda muffler.

The sound proofing box works very well but how do you cool the Honda when it is running inside the sound box?

Basic Thermodynamics

The load:

The Marvair AC operates at 12.67 amps and 110V or 1394 W which includes the raw water pump, to produce 16,000 BTU/hr. The surge load is not included in these calculations. I used the Dometic Smartstart device on the Marvair to reduce the surge load when the compressor kicks on. The Marvair SEER rating is thus 16,000/1394 = 11.48.Thus to operate the Marvair A/C using the Honda 110 V AC output plus its 12V output at 6 amps (72 watts) for air cooling blowers, the Honda must produce 1466W continuous power (1394 + 72).

To convert Watts to BTU/hr:

1BTU/hr = .293071 W

1W = 3.412 BTU/hr

BTU/hr = W / .293071

1466 W = 5002 BTU/hr

The Honda needs to produce 5002 BTU/hr of power to run the Marvair A/C [2].

The power source:

The Honda 2000 has a rated continuous output of 1600 W plus 6 amps DC (72 W) for the cooling inline blowers. On ECO mode the Honda produces just the current demand. It has a GX100 air cooled engine (98cc) which Honda rates at 22.5 % thermal efficiency. We can also use the formula for thermal efficiency:

TE= .0226 x HP/fuel consumption GPH.

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[2] How can an air conditioner which uses 5002 BTU/hr of electrical energy turn around and produce 16,000 BTU/hr of cooling power? The refrigeration capacity of the air conditioner has nothing to do with how much energy is required to move that much heat. The amount of energy needed to move the heat depends on the temperature difference the evaporator (cabin air temperature) and condenser (raw water temperature) coils are operating at, and the Coefficient of Performance (COP) of the air conditioner unit. The Marvair 16,000 BTU unit has a COP of 3.2, so will require 16,000/3.2 = 5000 BTU/hr (1466 Watts) electrical energy to operate it.

Honda rates the GX100 at 2.8HP at rated load (1696W) and 3600 RPM and rates its fuel consumption at rated load to be .28 GPH gasoline. Thus we calculate TE = .0226 x 2.8/.28 = 22.6%, very close to Honda's rating.

Waste heat:
Assuming the Honda has a 22.5% thermal efficiency when the Honda runs at the **Marvair A/C load (5002 BTU/hr**) then we can calculate the waste heat when running the A/C:

.225 (Total heat)= 5002 BTU/hr then Total heat = 22,231 BTU/hr.
Waste heat = Total heat - Honda output= 22,231-5002 = **17,229 BTU/hr**.

Heat transfer:
So how do we extract all this waste heat of 17,229 BTU/hr from the enclosed sound proof box housing the Honda? We have three methods of heat transfer available:

1. **Forced air convection** using the Honda's internal engine powered cooling fan plus two 3" inline 12V blowers sucking air out of the sound box and forcing it out the stern vents to the outside air.
2. **Forced water convection** using a the modified Honda muffler with copper tubing circulating raw water to cool the Honda exhaust system which then exits through a wet exhaust hose and out the hull just above the water line. See attached picture.
3. **Change of phase fresh water** mist cooling inside the box using a 12V pressure pump (1.9 amp)with one mist nozzle around the muffler/ exhaust manifold. This is only needed for real hot days and A/C load.

Forced water convection and wet exhaust

To raise one gallon of water 1 degree F takes 8.34 BTU. So if we use the forced water convection muffler with wet exhaust we can calculate the extraction of waste heat by knowing the amount of water flow and the increase in water temperature knowing that the Honda exhaust is ambient air temperature after going through the wet exhaust mixer**.**

To test the water cooled muffler I used a garden house tap water at a constant temperature of 80 F as the source coolant. I used a slower rate of flow catching the wet exhaust water in a 17 gallon tub. The exhaust gases and water at the exit of the wet exhaust were fully mixed and the exhaust

gases were ambient air temp(85F). I first warmed the Honda and then started the test **with a 1250 W load**. It took 15 minutes to fill the 17 gallon tub for a flow rate of 68GPH. The water temperature in the tub stayed at 90F throughout the test. Therefore the total heat removed from the Honda's exhaust/muffler system was:
BTU/hr = 10F x 68GPH x 8.34 = **5,671 BTU/hr.**

Change of Phase fresh water mist cooling

There are many mist cooling systems on the market which use fresh water to cool small areas and a 50 psi diaphragm pump (1.9 amps 12V). One mist head uses just .4 gallons of fresh water/ hour or 4 gallons over a 10 hour period. The measured hot air temperature exiting the stock air cooled Honda is about 145 degrees F. **Assuming one mist head will vaporize all its water when sprayed into this hot air then we can extract 890 BTU per pound of liquid water**. One gallon of water weights 8.34 lbs so one gallon of vaporized water extracts 7,423 BTU/gal of heat. Change of phase heat transfer packs the biggest punch. Since the mist nozzle sprays 4/10 gal per hour the extracted heat equals .4 x 7423 or **2969 BTU/hr**. This heat extraction is the same regardless of load.

Forced air convection cooling

The Honda internal cooling fan draws in cool air from openings in the sound box, forces it around the engine and then pushes the heated air out to the suction intakes on the inline blowers. We are using two inline 3 inch blowers in the Honda sound box. One blower moves 130 CFM of air at 13.6 V (3 amp). Two blowers operating from the Honda 12V outlet move only about 145 CFM of air due to static loads and lower voltage. We "suck" this amount of air out of the sound box to the stern vents and to the outside air.

We can calculate Sensible Heat (Q BTU/hr) as follows:

Q = 1.08 x CFM (T, hot out - T, ambient air)
T of the hot air out the stern vents = 150 F
T of ambient = 88 F
If all this forced air from the blowers was going out the stern vents (145 CFM) then Q = 1.08 x 145 x 62 = 9,709 BTU/hr. We know that the water muffler and mist cooling removes 5671 BTU/hr + 2969 BTU/hr waste heat or 8640 BTU/hr. So the total waste heat removed is 18,349 BTU/hr compared with the

waste heat generated of 17,229 BTU/hr.

We can cool the sound box and maintain a constant temperature even when the Honda is constantly running under almost full load.

Temperature and Carbon Monoxide (CO) tests. I started Honda and A/C at 8:00PM after a hot day. The outside air and cabin temp was 88F. The A/C thermostat was set at 76F. By 9:30 PM the stern vent air exhaust temp was 150F but the hand touch test on the Honda casing was just warm.
Readings:

Time	CO	Sound Box Temp	Cabin Temp
8:00 PM		Start	88F
9:00 PM	0	96.8F	83F
10:00 PM	0	95.2F	78F
11:00 PM	0	95.0F	77F
6:30 AM	0	90.0F	76F

The A/C compressor ran continuously from 8:00 PM until 11:30 PM to finally cool down the cabin after a hot day. The compressor than began to cycle on and off with the thermostat setting of 76F. The Smartstart on the A/C worked well and the Honda never kicked out. The water mist used about 3.5 gal of fresh water during the night (10 hrs). No smells in the cabin and it was a comfortable temperature. In the morning the Honda casing was quite cool to the touch.