how it works

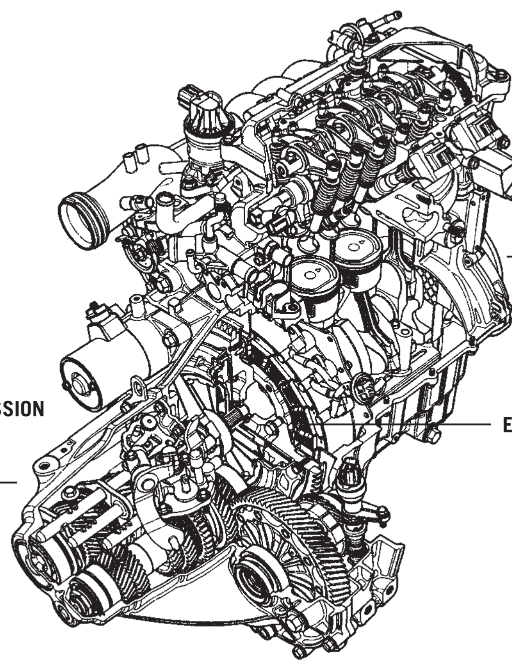
IT TAKES INTEGRATION OF MATERIALS AND AERODYNAMICS, IN ADDITION TO ENGINE, ELECTRICAL, AND ELECTRONIC LEGERDEMAIN, TO BRING THE FIRST HYBRID AUTOMOBILE TO THE US MARKET.

Hybrid gas/electric cars hit the streets

By Rick DeMeis, Contributing Editor

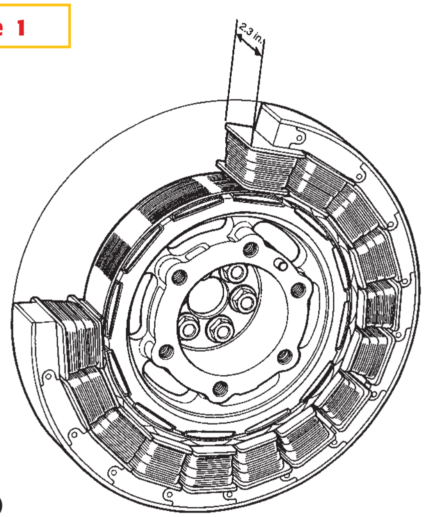
If you think a realizable, low-pollution, energy-efficient car hinges only on practical battery technology and electrical power management, you had better broaden your view. Honda engineers—under a prime directive of maximizing energy efficiency (read: fuel economy)—have tapped into many technologies to reach their goal and bring the company's hybrid gasoline/electric Insight to a showroom near you. Although such a car required the availability of the electronics and power system, the car now at dealers would have been impossible without a cornerstone internal combustion engine, material and fabrication advances, and attention to aerodynamic details (see **sidebar** "Going with the flow").

At the heart of the vehicle is the power train, consisting of a 1-liter, three-cylinder engine and a 2.3-in. (60-mm)-thick, electric-assist motor mounted between the engine and transmission. Operation and integration of the two is via the IMA (Integrated Motor Assist) system and its power-control unit (**Figure 1**). Power for the 10-kW, permanent-magnet motor, which serves a dual function as a starter, comes from a 44-lb (20-kg) NiMH battery pack, comprising 120 D-size cells putting out a total of 144V at a rated capacity of 6.5 Ahr. The gasoline engine weighs 132 lbs (60 kg), which Honda says is 20% lighter than other similar engines due to design



(a)

Figure 1



(b)

The Insight's IMA system comprises a 1-liter gas engine, the transmission, and the electric-assist motor (a). Because it fits neatly between the engine and transmission, the flat compact electric-assist motor has minimal impact on under-hood volume (b).

features, such as an integrated exhaust manifold/cylinder head, and lightweight materials (see **sidebar** "Insight by the numbers").

The batteries for the $18,880, two-seat Insight are behind the driver and passenger seats, beneath the rear deck, which is under the hatchback lid. The power-control unit, a high-voltage inverter, a dc/dc converter, an electronic control unit, and twin cooling fans reside next to the battery pack. Contrary to what many engineers believe when they first hear about a hybrid system, the electric motor is not the main propulsion source. The car runs primarily on the gasoline engine with the electric motor assisting in acceleration (**Figure 2**). In operation, the assisting motor adds power when the driver's throttle input places too high a demand on the gas engine. When stopping, regenerative braking charges the batteries. You can also charge the batteries from the running gas engine, if necessary. To preserve the battery pack, a small lead-acid bat-

Honda's Insight hybrid relies on a lightweight aluminum body and structure, along with plastic front fenders and skirts (top), to maximize gas mileage and provide crash protection with large-cross-section, extruded aluminum members (bottom).

GOING WITH THE FLOW

Meet George Jetson. Well, meet his car. That impression is the first one you have when seeing Honda's hybrid gasoline/electric-powered Insight (**Figure A**). The vehicle looks like cars of the future from the 1950s were supposed to look: sleek but not fast. Such an impression is due mainly to the rear fender skirts that make the car look clean (and are aerodynamically efficient) but add to a certain bulkiness of line.

But all the nuances of shape on the Insight add up to probably the lowest wind resistance ever on a production car: a drag coefficient (C_D) of 0.25. Today, most industry standards rate as "slick" any car with a C_D of less than 0.30. For comparison, the Honda Civic Hatchback, with about the same 1.9m^2 frontal area as the Insight, has a C_D of 0.36, which Honda engineers say translates into 32% more horsepower to run at highway speeds.

How did Honda designers manage to cut drag so much? First, they chose a basic teardrop shape because it naturally causes the least disturbance to the airflow going around it. The car cross section tapers from front to back, such that the rear wheels are 4.3 in. closer together than the front. And the rear fender skirts enclose the rear wheels themselves to smooth airflow. Because even smooth airflow over a teardrop shape eventually separates into turbulent flow, the body's line has an abrupt cutoff, or "Kamm back," where the flow can break cleanly and predictably from the body. In contrast, rounded bodies can have the flow separation point move fore and aft, depending on conditions, causing handling changes and also possibly generating lift and reducing rear-wheel grip: Witness the Audi TT Coupe accidents at high speeds on German autobahns before their engineers outfitted them with rear-deck spoilers.

Up front, Insight's low, rounded front end generates minimal turbulence—with a side benefit of an improved front view for the driver. As air moves over the hood, the hood's trailing edge and cowl send air over the windshield wipers, lowering drag-and-flow separation, and up the highly raked windshield.

But there is more to aerodynamics than meets the eye. The underside of the Insight is flat to smooth airflow and reduce drag. Fairings around those areas that need to remain open, such as the exhaust and fuel tank, direct the airflow for least impact. The designers then sloped the rear of the car bottom upward at a 5° angle to smoothly feed air from underneath into the low-pressure region behind the car.

Finally, to further cut turbulence, the Insight has small air dams in front of the front wheels, and the rear of the front-wheel openings are inset and have fairings, as well. Moving rearward, the lower sills along the sides extend downward, functioning as an air dam to limit airflow going underneath the car, which would reduce road-hugging low pressure.

At least with the Insight, form follows function resulting in overall operating efficiency.

Figure A

The abrupt Kamm back at the rear of Honda's Insight ensures clean airflow separation for constant aerodynamic forces on the car.

tery is available to run accessories and lighting when the gas engine is turned off.

DESIGN HURDLES

Koichi Fukuo, chief engineer at Honda's Tochigi Center, notes that packaging the IMA system was a challenge.

"We had a hard time making the [electric] motor narrower so that we could place it between the engine and transmission," he says. For the gasoline engine, he adds, Honda had to develop a new "lean-burn engine achieving better fuel efficiency than a direct-injection engine." He says the company thoroughly re-examined and re-engineered the engine, including its head structure, which is the integrated cylinder-head/exhaust-manifold design that saves weight, along with lightweight materials such as aluminum, magnesium, and plastic resin (for the intake manifold, valve cover, and water-pump pulley). Fuel induction is by an advanced version of the company's sequential programmed fuel injection. Injection timing and flow vorticity allow a "stratified" charge, which results in an overall lean mixture but generates a richer mixture near the spark plug for ignition and a fast-burning, stable flame.

Interesting design features on the engine target friction reduction. One is having the crankshaft axis offset 0.55 in. (14 mm) from the cylinder-bore axis. Thus the crankshaft does not lie directly under the cylinder. Thus, when the engine fires just past top-dead-center, the downward force on the piston and connecting rod is maximized (the rod is more in line with the cylinder axis) with minimal side force on the cylinder walls—cutting friction. Honda engineers say that this approach cuts internal friction as much as 3%. The designers saved 1.5 to 2% more friction by shot-peening the small skirts of the aluminum-alloy pistons. The resulting microscopic dimpled surface better retains lubricating oil.

LIGHTWEIGHT, BUT NO WIMP

The Insight structure is mostly aluminum. The engineers borrowed construction methods from the company's Acura NSX sports car and used extruded aluminum frame members (precisely bent with Honda-developed methods) and cast-aluminum connecting joints. The body is 40% lighter than a comparable steel body, yet Honda says the body has 13% greater bending rigidity and 38% more torsional stiffness. Fukuo says this stiffness is possible because the engineers increased the cross-sectional rigidity of the frame members. A large cross section has optimal distribution of wall thickness and seamless bonding. In addition, the frame layout, which transmits and disperses incoming forces, adds to rigidity.

In highly loaded areas, such as the front and rear subframes, the hexagonal aluminum frame members are large, internally ribbed sections. These sections also form part of the impact-energy-absorbing structure. How well did the Honda designers do in tailoring the Insight structure? The vehicle earned four of five possible stars in the National Highway Traffic Safety Administration front-impact tests. The agency did not test for side impact, but the company says the car is designed to meet 2003 standards for side-impact and head-injury protection.

According to company spokesman Art Garner, the company met its goal of maximizing fuel economy in a "personal and sporty coupe, suited for both highway and urban environments." Using the two-seat-coupe design allowed Honda to maximize efficiency, he adds. In 2001, the hybrid power train will be available in a Civic model in Japan, and Honda will in the near future expand into the US market.□

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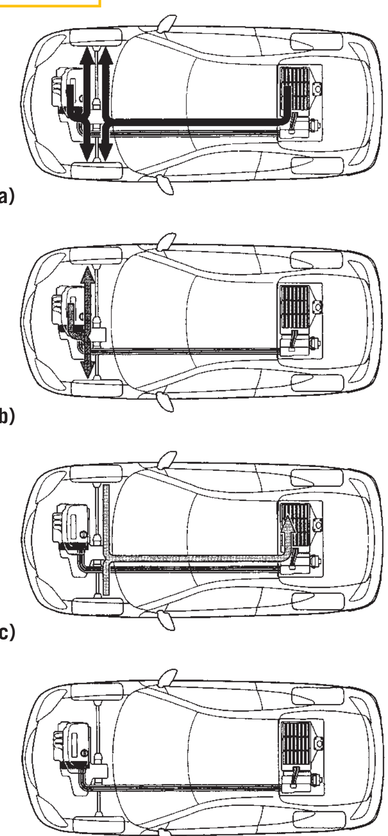
INSIGHT BY THE NUMBERS

- Engine/IMA (Integrated Motor Assist) electric motor: 995 cc/10 kW
- Horsepower (with IMA): 67 at 5700 rpm (73 at 5700 rpm)
- Torque (with IMA): 66 (lbs/ft) at 4800 rpm (91 at 2000)
- Fuel capacity: 10.6 gallons
- EPA mileage (city/highway): 61/70 mpg
- Curb weight: 1856 lbs (1887 lbs with air conditioning)
- Maximum load: 375 lbs
- Suggested retail price: $18,880 ($20,080 with air conditioning)

Figure 2



(a) (b) (c) (d)

The IMA system controls the electric-assist motor, which is mounted between the engine and the transmission. During acceleration, power to the front drive wheels comes from the gasoline engine and the assist motor (a). The gas engine alone sustains steady cruising (b). During deceleration and braking, the assist motor functions as a generator to regeneratively brake the car (along with conventional brakes), recharging the battery pack (c). Idling does not usually transfer power to or from the batteries (d).