Preparing for a Run at the Land Speed Record

John Sramek, ArticleTech, Santa Clara, California

The North American Eagle™ represents every hot rodder's Dream Car – take a fighter jet, remove the wings, put on wheels and then take her for a spin! This particular coupe is the brainchild of Ed Shadle and Keith Zanghi. Ed hopes to drive it and set the new world land speed record in fall 2006 or early 2007. The current record is 763.035 mph over a one-mile course, set by driver Andy Green and a British team in 1997 at Black Rock Desert, NV.

The conversion of a Lockheed F-104 Starfighter to a ground vehicle presents some unique design and structural challenges. Ed and Keith lead a team of 36 highly experienced engineers and technicians, who volunteer their time to solve the engineering challenges associated with the goal of achieving 800 mph.

The Starfighter was the first United States Mach 2 airplane. In 1958, an F-104 set the world speed record of 1404.19 mph, and in 1959 an F-104 set the altitude record of 103,395 ft. The Starfighter was the first aircraft to simultaneously hold world records for speed, altitude and time-to-climb. The first prototype was produced in 1954 and it was a mainstay of the U.S. and later, NATO air forces until the last front-line aircraft were retired in 2004 from the Italian Air Force.

The F-104 was well designed for high speed flight," according to Steve Wallace, chief engineer on the North American Eagle (NAE). "What we didn't know was how well it would do taxiing at 800 mph." After preliminary calculations verified the potential for the conversion, Ed and Keith began a search that lead to an aircraft dealer's hangar in Maine. There, they found the aging F-104 that would rise like a phoenix to become the North American Eagle.

Vehicle Conversion. Very early on, there were concerns over the structural stiffness, the modes of vibration of the vehicle, the suspension, and the damping properties of both the vehicle and the road surface. With the assistance of PCB Piezotronics (PCB®) and sister company Larson Davis, the NAE team was able to investigate and address these issues in preparation for the recently conducted desert trials at Edwards Air Force Base in California.

Early in development, they used simple shaker and impact-hammer testing to understand what they had to work with. ICP® accelerometers were mounted in key locations, and the aircraft, jostled as if rolling along the ground. Among the modes detected, a low-frequency, 11-Hz torsional mode was quite apparent. With this finding, the team realized that the flexibility the aircraft had in flight was not well suited to a road vehicle.

It was found that the nose wheel was acting as a fulcrum for certain modes, and that bouncing and dynamic stiffness were also problems. To be used as a land vehicle, the craft needed much greater support than that provided by the nose wheel and two rear wheels. The design of the NAE was also carefully analyzed with respect to the axial modes of vibration that had been detected.

The F-104 Starfighter has a forged keel beam in the bottom of the belly that runs nearly the length of the aircraft. This single structural member provides stiffness but allows the rest of the fuselage to be relatively flexible. To stiffen the fuselage and address the torsional mode, two 1/4 in. steel pieces parallel to the keel beam were added to create a much stiffer truss down the belly of the vehicle. Filling in the web of the truss with steel-powder-reinforced resin further stiffened the new keel. Due to concern over possible cracking of the new subassembly, the team monitors the condition of this new structural member using foil sensors.

To provide even greater support, it was decided to add two new wheels under the center of the car and to additionally move the rear wheels in a few feet. These were quite major changes, but moving the rear wheels in shortened the cord length and the two middle wheels provided the support needed to virtually eliminate the axial modes of vibration.

One of PCB's larger modally tuned impact hammers provided localized structural excitation and identified other modes of vibration. Rolling tests at 'low' speeds (to 300 mph) were then conducted at a municipal airport to gain a better understanding of rocking and flutter modes. Multiple PCB accelerometers were used along the vertical stabilizer and high on the fuselage to monitor flutter, z-axis and rocking axis motion.

Turning their attention to the new wheel configuration and suspension system, the NAE team conducted modal testing using a PCB-instrumented force hammer and Model 354C10 ICP® triaxial accelerometers mounted on the main spars, the axle, and on the arms supporting the mid-wheels. The results were used to analyze the suspension system and understand the effect of resonant and forced vibration. Static tests were then followed by rolling tests, and two PCB microphones were used during the tests to listen for unusual noise and vibration. PCB Model 377A02, 1/2 in. free-field prepolarized ICP condenser microphones, and Model 426A01 1/2 in. microphone pre-amplifiers were used. The acoustic results correlated very well with vibrations detected by driver Ed Shadle at speeds over 250 mph. The vibrations were caused by wheel imbalance addressed by the team prior to the Edwards AFB desert runs. The ICP accelerometers detected the same forced vibration and served to validate the forward velocity of the vehicle.

Figure 1. Designed to win the coveted North American land speed record, the North American Eagle™ is a converted F-104 Starfighter. In trial runs, it was instrumented with more than 50 PCB accelerometers, microphones, and strain gages to collect real-time data.

Figure 2. Lockheed's F-104 first appeared in the mid-1950s and was the first operational interceptor capable of sustained speeds above Mach 2 and was the first aircraft ever to hold the world speed, altitude, and climb records simultaneously.

The converted NAE vehicle is 56 ft long, weighs more than 13,000 lbs and is powered by a General Electric LM-1500 Turbojet engine (a derivative of the J-79 engine originally used in the F-104). The stock engine for low-speed testing produces 42,500 hp, but a second engine that will be used for the record run has been enhanced to produce 52,000 hp. When idling, the stock engine consumes about 40 gallons of jet fuel per min. This increases to 80 gpm at 100% thrust, and when the after burner kicks in, the fuel consumption reaches 160 gpm.

Although the extensive modifications to convert the aircraft to a vehicle were verified for relatively slow speeds at an airport, the record runs must be conducted on a longer and softer surface at the Black Rock Desert. Desert conditions add additional real-world factors, including dust, heat, foreign objects and debris not found on the relatively controlled environment of an airport runway. To gain experience in a desert environment, the US Air Force is allowing the NAE team to use runway 15 on the Rogers Dry Lakebed at Edwards AFB, the alternate space shuttle landing runway, to prepare for Black Rock.

Desert Tests at Edwards AFB. Tests were conducted October 24-28, 2005, at Edwards AFB to "shake-out" the on-board data collection system, the telemetry, the suspension, the hydraulic system, the new magnetic brakes and the parachute system. The real-world experience was invaluable, and several systems were modified during the five-day trials. In addition, dust collected in junction boxes, affected one of the two parachutes, and accumulated in other systems so that dust-proof shields will be used in future trials. During the runs, over 70 channels of data and sensor signals were collected and will be used for on-going analysis of the NAE's performance.

To digitize the sensor signals and analyze the huge volume of data, the NAE team used three Larson Davis digital sensing systems (DSS). The DSS systems allow them to collect and store all the data in RAM for later review. In addition, the team used the microphone inputs on the DSS systems for real-time analysis of 30 channels, whose data were telemetered to a chase vehicle shadowing the runs. The DSS systems easily accommodate traditional AC-coupled inputs, such as accelerometers and microphones, but the team has also collected strain gage, tachometer signals and other DC coupled data with the DSS during testing for correlation of vehicle parameters. In analyzing and viewing the data, DSS systems are very flexible in measuring and computing FFTs, distribution data, time history data and cross channel measurements. The test runs at Edwards AFB lasted less than 120 sec, so the real-time digitization and analysis capabilities of the DSS were essential in the collection of data.

Results. The successful October desert trials provided a wealth of information and data on the performance of the North American Eagle. In the coming months, critical modifications to the vehicle will be made in preparation for intermediate speed runs (400 to 500 mph) at Edwards AFB planned for June 2006.

Information on the continuing progress of the NAE is available on the team's website at www.landspeed.com, and information on PCB Piezotronics products is available at www.pcb.com.

North American Eagle™ is a trademark of the NAE team. PCB® and ICP® are registered trademarks of PCB Group, Inc. All other trademarks are the property of their respective owners.

John Sramek holds a Bachelor of Science degree in Electrical Engineering from Bucknell University, as well as a M.B.A from Santa Clara University. Prior to joining ArticleTech, a full-service article writing company, John worked with GenRad, Harris Semiconductor, Exar, and Xicor. John can be reached at: John@articletech.com.