Inspiring Innovation In

VEHICLE DESIGN

A Retrospective of Michael Seal and WWU's Vehicle Research Institute

Edited by Eileen Seal, Barbara Sylvester, and Kathleen Kitto
with contributions from
WWU faculty and Michael Seal's family, friends,
and former students
Cover Design – Cathie Clutter
2004

To the Memory

of

Major William (Bill) Brown
1919-1995

Enlightened Educator
Master Machinist
Dear Friend

CONTRIBUTORS

Lionel Archdale, Former Student

Patrick Brown, Michael's Best Friend from Childhood

Lisa Seal Christensen, Michael's Daughter

Cathie Clutter, Michael's Daughter

William Connelly, Former Student and VRI Research Assistant

Cole Dalton, Former Student

Clyde Hackler, Retired Engineering Technology Chairman

Claude Hill, Retired Engineering Technology Faculty

Helen Hughes, Michael's Sister

Tom Hull, Former Student

Kathleen Kitto, Associate Dean, College of Sciences and Technology

Suzanne Lautenbach, Michael's Daughter

Eric Leonhardt, Former Student, Assistant VRI Director

Stan Miller, Former Student

Sam Porter, Retired Engineering Technology Faculty

Tim Roddick, Former Student

Eileen Seal, Michael's Wife

Georgia Seal, Michael's Daughter

Ronald Seal, Michael's Father

Craig Selvidge, Former Student

Randy Weaver, Former Student

Wes Williams, Former Student

We are grateful to all these contributors who have provided memories of the VRI and Michael Seal. Their pieces, each prefaced by the words "***I remember,***" the title of the piece, and the author's name, are entered as far as possible in the individual chapters describing the project, rally, or car with which their memories are associated. (Some contributors have entries in two different chapters.) Except for Chapter 11, the book is arranged chronologically.

CONTENTS

FOREWORD

by Sam Porter

Producing a tribute about the career and contribution of Michael Seal is a daunting task for several reasons. First, it is difficult for mere words—especially mine—to adequately summarize and portray the enormous contribution, energy, intelligence, and achievement which has characterized Dr. Seal's time at Western. Secondly, a tribute statement alludes to some sort of conclusion to Dr. Seal's work at Western, and "conclusion" is not a word that describes Dr. Seal and his work. He is not likely to conclude his contribution to Western any time soon (one expects him to be back in the laboratory by the next working day), and "conclusion" does not describe the lasting nature of his inventions, solutions, and achievements, which are, in many cases, so advanced that they will provide major usefulness for a long time to come. Moreover, "conclusion" is not a word that describes the lasting influence he has had in inspiring and energizing students for many years; his influence will live on and on.

I have often wondered what forces made Dr. Seal want to come to Western, first as a student for coursework which often offered content below his level of learning and dignity, and, later, as a faculty member who could easily find a career in a more prestigious institution. However, in the long view, Dr. Seal at Western made an almost perfect fit for both. As Western emerged from its original role as an undergraduate teacher-preparation institution, confusion often reigned in defining goals and roles as a scholarly, research, and academic university with loftier missions than the mere preparation of teachers—especially vocational, technical, and industrial education teachers. Some would see vocational/technical teacher education as the antithesis of the liberal arts. Yet, somehow, despite vacillating goals and sometimes raging arguments between the extremes, Dr. Seal seemed to be challenged by both aspects: he not only easily entered and upheld the high scholarly standards of a liberal arts institution but also raised the level of vocational pursuits to fit within that context. If higher education is not to be drawn into the old "thinkers vs. doers" dichotomy, it is incumbent upon institutions like Western to encourage the highest scholarly endeavor and to apply these standards and insights to the practical problems of emerging society. The early and notable pioneer scholars of Western (Woodring, Flora, Hicks, and Taylor—to name a few) contributed to and vociferously supported the activities of the Department of Industrial Arts. It is little wonder, then, that Michael Seal chose to enter this milieu and was a perfect fit. (Of course, the attraction to Western's environment had to include some infrequent but satisfying sailing in and around the Puget Sound.) With the creation of the Vehicle Research Institute (VRI), Dr. Seal and his followers were able to confront the major issues of the automobile and its environmental, societal, and engineering frontiers by interfacing with scholars from many disciplines, a cooperative opportunity sometimes lacking in major engineering schools where these disciplines and fields are often distant and separated.

Early on, and throughout his career at Western, Dr. Seal became known as a teaching professor of the highest order. Buckminster Fuller once remarked that a truly great teacher can explain any subject on earth to any level of learner (even though Fuller, himself, was often difficult to understand). Dr. Seal could take almost any problem in the pursuit of automotive excellence and subtly entice learners to assume the problems as their own and to work ceaselessly toward solutions. When my nephew, a liberal arts graduate from a prestigious eastern college, did fifth year work in the VRI, he became so involved in his work with Dr. Seal that he later started his own hugely successful company doing similar work. His wife stopped by the VRI lab to give a message to her husband and soon found herself engaged in designing and making composite wheels. Guests have always swarmed into the VRI labs because Dr. Seal has always welcomed visitors with calm enthusiasm for both the visitor and the work of the labs being viewed. He has always taken time to explain technical details and achievements cogently and without the impatience most researchers might be inclined to demonstrate.

One of Dr. Seal's characteristics which I always admired and appreciated was his "Can-Do" (Canadian?) demeanor. When the Technology faculty was confronted with proposals (from the sublime: "let's create a completely new Department structure," to the ridiculous: "let's clean the basement"), Michael Seal could be counted on to be the first to go beyond "yes" and to show up to get the work done with enthusiasm and energy. Michael Seal changed the old saw, "Fools rush in" by making a fool of those who would hesitate. In recent years, his contagious enthusiasm ensnared his wife, Eileen, in the work, and her enormous contribution to the work of the VRI should be lauded.

The research dollars, the ambitious series of automobile developments, the entries and successes in internationally known competitions, and the importance of cutting edge achievements in vehicle innovation have made Dr. Seal known and, just as important, have made Western Washington University widely known for this effort. I have encountered various engineers and experts in many parts of the world who have read about Western's VRI and marveled at such achievements from a small public university in this fourth-corner source, far from major automotive centers. On a flight from Indonesia to Singapore, I met a Chinese engineer who was carrying an article about the VRI in his briefcase. Needless to say, such encounters have always made me most proud to be a part of Western and its history, and to have served at a time when Michael Seal was setting the pace for us all.

Sam R. Porter, retired Engineering Technology Dept. Chairman, is a friend and colleague of Mike's.

A Tribute to Eileen Seal

by Kathleen Kitto

No history of the Vehicle Research Institute would be complete without a tribute to Eileen Seal. When I first arrived at Western's Technology Department in 1988, I noticed that there was always a pleasant woman in Mike Seal's faculty office or in the VRI labs who appeared to be organizing everything and taking care of all things, both big and small. I quickly learned that this person was Mike's wife, Eileen, and that she was a VRI volunteer. It didn't take me long to get to know her, as I took my first trip with Mike and Eileen that same fall. We took the "red-eye" to Florida and drove all the way to Detroit in two days in order to take road incline data for Viking XX's eventual route in the upcoming "Sunrayce USA." Not only did we have a great time on that trip, but I really began to notice how Eileen was taking care of us in her own quiet and gentle way. I didn't have to do anything except take the data. Eileen had the whole route planned, had the tickets to everything, had places to stay identified, and knew about when we would eat or need a break. She just did everything for us. Everything! She has been taking care of us all these years and has never really asked for anything in return. There probably were hundreds of times we complained or forgot to thank her, but she has been always there and always willing to do anything to help. (However, I will say that even Eileen did not know that boiled peanut stands were not everything they said they were in Georgia.)

Eileen is that rare and special person who is willing to serve others. There are not many people who are willing to give everything, so that others may benefit. Eileen has always been such a big part of the VRI that probably much of what has happened would not have happened at all without her hand in the background. Whether it was finding the right tool at the last minute at Hardware Sales and running to get it or scraping the rough edges from the sides of solar cells, she has been there on every step of the VRI journey. We could never have gotten along without her in all these adventures.

I have always thought it was revealing that friends of the Seals refer to them as "Mike and Eileen" and that they say it as if "Mike and Eileen" were just one word. I suppose that is really how I think of them, too. They are somehow two parts of the same whole, supporting and complementing each other. Mike's enduring and deep affection for Eileen has always been apparent to us, too. It has been wonderful to be a small part of their joyful and extraordinary journey through life together. Here's to you, Eileen! We could not have taken this journey without you. Thank you, because I forgot to say it many times along the way. We love you, because we did not say it before to you.

Kathleen Kitto is the Associate Dean of the College of Sciences and Technology and a friend of Mike and Eileen's.

CHAPTER 1 — Michael Seal

Childhood, Best Friends, First Cars, Marriage, and Fatherhood

We remember . . .

Scenes from Michael's Youth

by Helen Hughes, Michael's sister, and Ronald Seal, Michael's father

Two themes have twined through the life of Michael Ronald Seal. One is food and the other is wheels.

When Michael was very young, his father started to make him a kiddie car, a small three-wheeled vehicle that is propelled by a child sitting on the seat and walking it along. The moment Michael set eyes on the wheels, he cried out, "Go, Go!" Those were his first words. When the kiddie car was finished, he called it "Ghee Gar."

Michael and Ghee Gar

Not long after that, Michael caught on to the fact that when his mother inquired of his father if he would like an "E double G" for breakfast, it meant he would get an egg. "Ubble Gee, Ubble Gee" Michael would shout, bouncing up and down in his high chair. When he was still a wee lad, he found his way next door to the home of an ample and generous neighbour who sat him on her lap and fed him cookies.

"He thinks I am a chesterfield!" she said fondly to my mother, who came to fetch him. When he was just big enough to peer over the edge of the table at dinner time, he would exclaim enthusiastically, "Golly flower, oh boy, oh boy, oh boy." He has never lost his appreciation of good food, and I suppose it is no accident that his wife, Eileen, is a gourmet cook.

His great curiosity caused the occasional difficulty in Michael's life. Once when he was about three, our mother dressed him in a lovely little yellow suit of leggings and sweater that she had just finished knitting. We were all coming home from a walk when the path wound by an old shed. Michael wanted to go around the shed the other way, while the rest of us carried on along the path. My parents let him go, only to find, to their horror, that he had discovered a can of old nails and had quickly become covered in rust from head to toe.

When he was three, Michael heard his father being interviewed on the radio. "Get Daddy out of that box," he cried, in great distress.

When Michael was getting a bit too big for Ghee Gar, my mother saw an ad for a second-hand tricycle which she rushed out to purchase. He was thrilled. I was given Ghee Gar, and was heard to mutter ungratefully, "I..... want..... bedals."

Michael's Parents – Ronald and Olivia Seal

Always ready for adventure, Michael and I dug a big hole in the middle of the back lane. He did the spade work, and I did the dragging of cardboard to cover the hole. We sprinkled the top with dirt. When the police came to the back door, I explained to my puzzled parents that we had built "a neat little scare."

Michael's love of cars emerged again as he got big enough to build models and race them down the sidewalk. One time he dragooned a little red plastic teddy bear of mine to "drive" the vehicle. When we and the car all got to the bottom of the hill, the teddy was nowhere to be found. We searched everywhere, but the teddy bear had disappeared. It was my first experience with the paranormal.

A bit later, Michael started building Go Karts which were called Soap Box Racers. He entered the Soap Box Derby, and excitement ran high as Racers rolled down the hill with varying degrees of success. I remember that one contestant used baby buggy springs on his Racer, which seemed to give him quite an advantage. There was great debate about the "fairness" of this innovation—a portent of things to come.

Michael With His Soapbox Derby Car

When Michael was old enough to earn money here and there (did he have a paper route?), he saved his money and bought a Sunbeam bicycle. He ordered it from a catalogue. It was shiny and black. For weeks, while he was waiting for it to arrive, he had recurring nightmares of getting on the bike and then having it turn to limp spaghetti beneath him. Finally it arrived, and he rode it up and down the block, glowing with pleasure. I envied the beautiful silver bell.

Michael's early school career was not stellar. He never quite made it into the igloo, on to the list of champions, or through the gateway of good spellers. Once, when he arrived home without his schoolbooks, he said vaguely that he had lost them. Our canny mother backtracked and found them stuffed down a sewer drain. He did learn to read, however, and devoured everything he could get his hands on, including a book by Frank Yerby that an unwitting maiden aunt had sent because it had a picture of a pirate on the front. She must have missed the picture in the background of the lusty maiden with the torn bodice.

In 1950, when we moved to North Vancouver, we felt we had left civilization as we knew it. There were no sidewalks, but mostly just dirt roads and plenty of forest. We lived next to a ravine, where Michael built a fort in the trees. When we wanted to camp out overnight in it, our father came to inspect it to see if it was substantial enough. It was. The four corners were living trees, and the fort was built from logs, notched to make a sturdy little house about 6 foot by 6 foot, with a hinged door and two bunk beds attached to the walls.

We both spent a lot of time down by the creek, and this is where Michael met his lifelong best friend, Paddy. Paddy lived on the other side of the ravine, and they both happened to be at the creek at the same time. Words were exchanged, then shoves, and Michael was pushed into the creek: the perfect start to a long friendship.

Both Michael and Paddy were interested in cars, a natural extension of their love of wheels. Michael's first car was a Morris Minor, and we could hear him coming from about ten blocks away. He and his friends built racing cars, the first being Genesis. They raced out at a track called Westwood. The car would line up with the other contestants, and all of its fans would stand enthusiastically cheering it on from the sidelines. Off they would all roar, around the bend and out of sight. After a bit the lead car would hove into sight, then the next and the next. Genesis would not appear, but quite some time later a weary driver would plod back to tell the crew that she had broken a fan belt, blown a gasket, lost a wheel, or split a fuel line. It was all very exciting!

The boys all took a fancy to a Czechoslovakian car called a Tatraplan. It looked like a fish, and had a fin down the back. The engine was in the rear and exploded with flame at regular intervals. One day we had five of them lined up in our backyard, and they all were running! Because it was impossible to find parts for this very strange vehicle, every owner had to have the car that he tried to keep running, and then several others to butcher for parts. Between them they had the majority of the Tatras in Canada. When the boys moved to more sophisticated cars, and the age of junkers had passed, our father dug a huge hole in the backyard and buried all the Tatra remains therein.

Tatras
From Left to Right—Tom Spouse, Jim Broughton, Allen Whaley, and Michael Seal

Whenever our group of friends went somewhere, at least one of the cars would break down. More time was spent under the hood than in the car. Late one *night our mother received a call from Michael saying that his car had broken down, and he had just extricated a strange girl from the Capilano River. Out she went to rescue them. It turned out that our mother knew the girl's family, their background, and even the history of their surname which had been "Smelly" before they changed it to "Smiley." That was a short-lived romance.*

Having been a Cub and then a Scout, Michael became a Rover. He also helped out with a Cub Pack. One day he scrounged a rather large bone from the butcher to use on a totem stick. As he boiled it to get the meat off, he thought it would be a waste not to use the stock, so he invited several friends to come over for lunch. When Mother arrived home from church, she was greeted by hungry teenagers peering into a pot of grey water. We had no idea what to do with it! Pretty soon she had everyone chopping and grating, and before long a lovely soup emerged.

We used to have square dances in our basement when we were young, and later ours was the house to host the parties. This is where Michael and Eileen first crossed paths. "Sardines" was a favourite game, where all the lights were turned off and one person went to hide. When you found the person, you squished in with him or her until everyone was there but the last person, who then had to be "it." It was an excellent game for getting cozy. I can scarcely believe now what we considered to be "racy" behaviour.

Time went on, and the remains of the various cars that were buried in the backyard rusted through and began to collapse. One day our mother was innocently wending her way to the compost heap when suddenly she found herself hip deep in a hole. The revenge of the Tatras.

I remember . . .

Five Tales of Friendship and Cars

by Patrick (Paddy) Brown—Best Friend

Mosquito Creek

The first scene is set in a leafy glade, in fact, the bed of Mosquito Creek, in North Vancouver, B.C. A couple of Sunday-dressed ten-year olds are innocently exploring the tangle of salmonberry bushes and mossy tree roots that border the creek. In those days, it was a clear salmon stream rushing over boulders of multicoloured granite, just wide enough to make crossing it an adventure in rock hopping and possibly wet feet. A sun-dappled idyll indeed. Cue the sound: a little wind in the trees, and the occasional splash-thock! of a boulder relocated in an effort at re-engineering the water flow.

Michael Seal, with his friend Geoff Mott, was exploring the creek bed, a potential new adventure ground, as Michael's dad was building a new house on the west side of the creek—foreign and possibly alien territory, since there were few bridges over the creek in those days. But hark! Who should approach from the east side of the creek but three disreputable delinquents of about the same age, indignant at this unauthorized invasion, but at the same time sensing opportunity in this serendipitous meeting. We were (at least one of us was) a little bigger than they *were. And there was one more of us. And we were demonstrably disreputable. It was, after all, our creek, and these two innocent strangers needed, nay, cried out to be acquainted with the fact of our possession. Which we did. The exact details of our encounter are properly lost in the mists of time. But it seems that the two Sunday-dressed returned to the building site, dripping and muddy.*

They soon came back, with parents, on a sort of search-and- destroy mission. We retreated up the bank on our side, and recruited appropriate parents, one of whom was, as I remember, a large Vancouver fireman with flaming red hair. But by the time we returned to the creek, they were gone.

And that was the start of a friendship, firm to the present day. Which just shows that pushing someone in a creek is not necessarily a bad way to begin.

Making things

Michael's dad built everything. After the house was finished, there were furniture, tools, a couple of sailboats, and another house, and so on. He's still making things, long retired from his job as the shop teacher's shop teacher. Readers who have survived junior high school shop, particularly as it was perpetrated fifty years ago, will recognize the simple tasks of producing a non-wobbly stool, or filing, seemingly forever, a piece of mild steel to make a coat-hook or some such insignificant and unwanted artifact of domestic hardware, destined to be forever relocated around the house for decades. Too much emotional freight hung upon it; it could not be thrown away.

I always got a D in shop. This fact, recorded on report cards, means that I can report with justifiable certainty that everything I learned about making things, I learned at Seal's. The basement of the newly built house was, of course, full of an astonishing variety of tools, woodworking and metalworking, the source of exquisitely precise items of joinery which marked the house as the home of a craftsman. Michael came by his skills in making things honestly, from his dad. I came by mine dishonestly, and it has always showed. But just from hanging around, I learned a lot.

There were garage doors into the basement, but no vehicle ever crossed that threshold. Too much stuff in there. It was the workshop. So soon there was a garage in the back yard. It was, of course, not big enough to build a boat in, so soon there was a bigger garage, a massive timber-framed structure rivaling the house in size. (Well, maybe not quite.) If I remember right, the boat came first, a 32 foot yacht named “Olhiyu.” It's still sailing—I see it once in a while. Built solid, as they say. Seal solid.

But this narrative is about cars. The first Seal vehicle I remember was a '”soapbox derby” vehicle, back when the pushers rode on the back, there were few rules, and the racecourse was between Prospect Point and Third Beach in Stanley Park. The secret, it turned out, was to make your soapbox racer as heavy as possible, so that once it had gathered momentum down the winding, bumpy asphalt, nothing would stop it. Soapbox derby cars nowadays are built to identical plans, with identical wheels, and raced down dead-straight courses—strictly for wimps.

Back then, with the crowds cheering the edge of the road, the races resulted in real physical injuries and environmental damage. Blood was spilt; trees were uprooted.

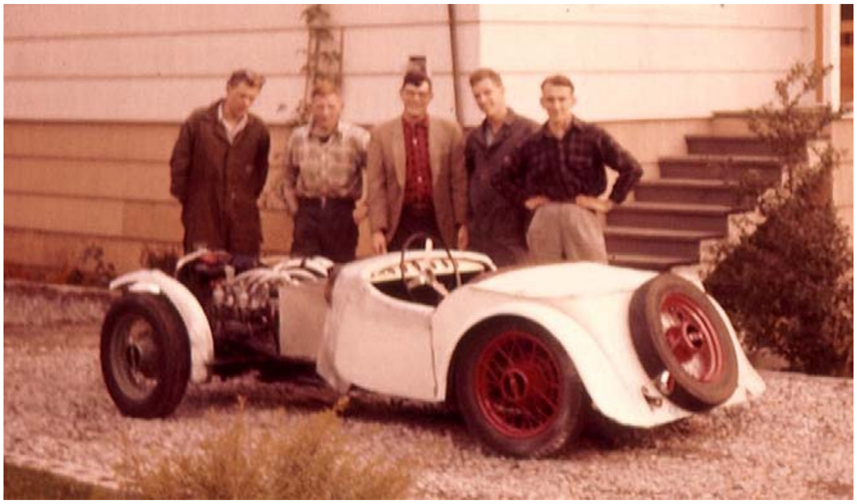
But real cars were coming. We would soon be old enough to get drivers' licenses. My dad bought me a 1942 Austin Eight. It had no shock absorbers, rather vague steering, wheels, tires and fenders from the balcony of an old dance-hall down on Main Street which, inexplicably, had become a junkyard specializing in British cars. The Austin Eight had a flathead four-cylinder engine which had to be revved to stratospheric height to get any performance. I remember cornering on Marine drive in West Vancouver, assisted by Michael leaning, motorcycle fashion, out of the passenger side window. I drove it to school for a year or so. At 92,000 miles, the crankshaft broke. Michael found another crankshaft and installed it, but I suspect it had also done its 92,000 years.

Then followed the Morris Minor years. The pur sang Morris Minor was the 1949, designed by an Englishman named Alec Issigonis and featuring such advanced features as rack- and-pinion steering, and an independent torsion bar front suspension with joints that wore quickly to a point where they went "bobbledy bobbledy bobbledy" as you went over bumps. Mine was a bright blue two-door, dead stock except for an Austin-Healey muffler that didn't quite make it sound like an Austin-Healey. Michael's was a black convertible, but he rebuilt the four-cylinder flathead engine with a Roy Shadbolt reground camshaft and stronger valve springs. It produced phenomenal revolutions per minute. The Morris Minor handled and cornered remarkably well, particularly if you lowered the front suspension, as Michael had. And, of course, the Austin-Healey muffler.

Genesis

But the Morris Minor wasn't a real sports car, not like the wire-wheeled, clamshell-fendered, long-hooded MG's then being imported from England, or the then new Austin-Healeys (of which we could barely afford the mufflers), or Jaguars, legendary even when they were new, or Triumphs. These cars were raced several times a year at the Abbotsford Airport, along with a variety of home-made 'specials' which could also claim traditional British roots. We couldn't afford any of these. But down the bottom of Fell Avenue there was a 1936 Morris Eight convertible for sale. I forget what we paid for it—it could be the price was negative—but I believe that it made it into the Seal garage under its own power. (From then on I can remember it doing little else under its own power.) But the Morris could also claim traditional British roots. And it did have hydraulic brakes. And, of course, a flathead four-cylinder engine with a single SU carburetor.

Old hot-rodders will remember that the standard treatment for a '32 Ford roadster was chopping, channeling (lowering the body over the frame), and lowering the suspension. Well, that's what happened to the Morris Eight. It came with cut-down doors, wire wheels (sort of), and a chrome windshield. We took it apart (easy, given the rust) and chopped, channeled and lowered it until it had the approximate appearance of a somewhat flattened MG TC. With cycle fenders on the front, and the spare wheel on the back, it could not have been mistaken for anything other than a pure sports car. After all, the driver sat more or less on the floor, and the *windshield had become a small piece of plexiglas. There was even a seat belt. And great big chrome headlights, from a Model A. It was named (again, a British tradition for “specials”) “Genesis.”*



Genesis
Left to right Tom Spouse, John Tones, Michael Seal, Dick Hughes, and Patrick Brown

And then the engine—still, at this stage, the flathead four, less than a litre. Michael had learned to weld by this time, and constructed a manifold that would take two SU carburetors. The head was shaved by an obscene amount to raise the compression ratio. As for the exhaust: we were disciples of a book by one Philip Smith, who first described the “tuned length” effect of exhaust and intake systems to increase horsepower. The exhaust system, then, was four pipes of the appropriate length, made of flexible conduit, and all welded to come together at the end. They looped over the engine in exotic curves. When the engine was started (not an easy task in itself) they smelled and smoked for some time until they set. It looked most impressive, and at the appropriate RPM made an ear-splitting racket.

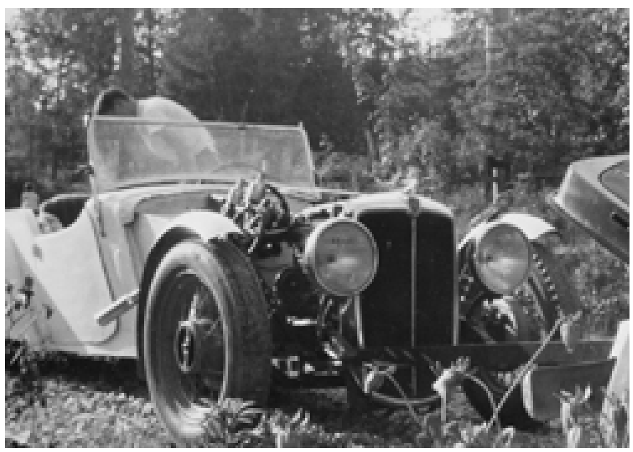
Genesis made one appearance at the Abbotsford races. As tradition would have it, work on the car (things like hooking up an oil pressure gauge) proceeded all the previous night, until it was time to tow it out to the racetrack behind John Tones' '41 Ford. Once there in the bleary-eyed morning, we started it. Its initial stutterings, punctuated by occasional backfires, attracted a large crowd. Michael was in the driver's seat attempting to keep the revs up (we didn't know how far up, because we didn't have a tachometer). I was attempting to get the two SU carburetors to behave as if they were acquainted. The noise was, as required, painful to the ears. There seemed to be something wrong with the ignition timing. I loosened off the bolt on the distributor and twisted. The engine stumbled, caught, screamed. People came running.

Then a new sound joined the cacophony. It seemed to be coming from the crankcase. I yelled at Michael, who had the accelerator firmly on the floor, "Turn it off!" He indicated, via sign language, that he had not received my message. "Turn it off!"   No response. But the noise became suddenly louder, and then its source, a *connecting rod, made itself apparent through the side of the engine. A number of other unusual noises followed. The engine shuddered to a halt.*

Members of the surrounding crowd wiped the oil off their faces and, after inspecting the damage, turned away, murmuring, as if they had just attended the funeral of a deceased relative. We never did make it onto the track that day.

A month or so later, Genesis received a new heart: a Wolseley eight engine, which was the same as the old Morris except that it had pushrod actuated overhead valves. A significant technological advance. It also had a Shadbolt camshaft, a grind so wild that even Roy Shadbolt had his doubts. It also had two vertical SU carburetors, equipment so exotic that nobody had ever seen one before. I don't recall it ever running or racing. Maybe Michael does.

Genesis occupied the back of a number of garages on the North Shore until we lost track of it. Then three or four years ago, someone phoned to say that they had this car and were restoring it and where would they get patterns for the convertible top? That was a hard question to answer.



Genesis

Tatras

Michael was never afraid of exotic cars. After the Morris Minor stage (many of our friends had Minors), I think, if I have the order right, there was a Citroen DS21. This plush French sedan was unnecessarily complicated, I thought, by a hydraulic system which not only controlled the suspension, and would jack it up and down, but also seemed to be essential to practically anything else the car would do. Michael insisted that it was totally reliable. I had my doubts, particularly as its failure mode saw it lowered firmly to the ground, like a tired spaniel.

But somewhere in here came the Tatras. In 1950, in return for a shipment of Canadian butter to a Czechoslovakia short of hard currency, Canada received fifty Tatra automobiles and a whole lot of Skodas. These were sold to the public through Campbell Motors, 1234 Kingsway in Vancouver, a well known used car dealer. Tatras had, I believe, originated in the late thirties, designed by Hans Ledwinka, and bearing a remarkable resemblance to a Volkswagen. Except that they were bigger and more rugged; in fact, they were damn near indestructible. A rocket-shaped, *double-skinned, four-door unit body, transverse leaf spring front suspension, torsion bar swing axle rear suspension, and a two-litre, four-cylinder air-cooled engine at the rear. Lots of ground clearance, and oversteer galore. A somewhat doubtful electrical system. (I remember in one rally, steering by a single flashlight in the middle of the night over the MacLeod Lake Road in the Okanagan, we left the road, went over a pile of logs, crossed a railroad track, and crashed back on the road again, having passed several surprised cars through this maneuver.) When Tatras started coming on the used market (it didn't take long), Michael bought one. And, following his lead, so did many of the kids we knew—I may have been unique in never owning one. If you have something exotic like that, you know they breed, and attract others (just a spare one for a parts car); at one time I think some 17 of the original 50 were close by. That was about the time that racing was dominated by Ferraris (which few of us had ever seen in the flesh) and the Porsche 550 Spyder.*

It wasn't long before it occurred to Michael that the Tatra contained nearly all the parts required to construct a sort of homemade Porsche 550. As I recall, this car even started with drawings (Genesis had never had drawings). A substantial tubular frame, the crown and pinion reversed in the transmission so the engine could be placed ahead of the rear axle instead of behind, and the rest of the parts were Tatra.

The unusable body was hard to dispose of, not succumbing easily to attack by cutting torch. The race car had a 'Micron' fiberglass body which came from England and was clearly proportioned for a front-engined car, which this wasn't. However, it looked not bad, and even respectable with a decent coat of paint. The seating was a couple of pieces of plywood, and uncomfortable. The brakes were still Tatra, and though they were fairly good sized drums, not up to the discs which some people were now using.

Michael raced the Tatra at Westwood, and then decided it didn't have enough power. He next installed a Chev 283 truck engine, totally unmodified except for a variety of extra carburetors. This addition necessitated lengthening the car a bit, but it made a reasonably frightening vehicle. It is still being raced in that form today.

California

In those days, California was the Holy Grail of sports car racing. I remember two trips with Michael. The first was in my 1949 Rover 75, a vehicle of such gentility and dignity that its high oil consumption could be completely overlooked, except for the five-gallon cans of oil that filled the trunk. The Rover, dark green, long hood, very vertical, four doors, very British, in fact very comfortable, had a few other eccentricities. The front suspension was a sort of independent swing axle located by very long radius arms which were pivoted on the frame near the transmission. These pivots would become loose from time to time, allowing the front wheels to wobble a bit when they went over a bump and eventually to precess into a totally uncontrollable dance which would see them both leap several inches off the road. Jamming on the brakes would usually cure this problem, and then crawling under the car and tightening the pivots—till next time. But the Rover was good on smooth *roads, not very fast, but quiet with a six-cylinder F-head engine (no, I don't have time to explain that right now).*

That trip saw us visit a number of the shrines of hot rodding. We went to the Jahns piston factory to order some high-compression pistons for the Tatra. We went to Pebble Beach to see the road races. We even visited the Ferrari dealer in downtown Hollywood and saw some real Ferraris close up. Once we drove into a gas station and had all the windows washed, the tires checked, the radiator topped up, and the oil checked by a most attentive group of attendants. They thought we were driving a Rolls Royce. We did buy gas though. We got stuck in a traffic jam on top of the "stack," the multi-level freeway interchange in the middle of Los Angeles, and opened the sunroof on the Rover to climb out and take pictures of stationary automobiles as far as the eye could see. And we drove California's Highway 101 coast road, not so much for the thrill of the drive but in order to see all those shiny sports cars bombing up and down. What a sight!

When the oil consumption of the Rover started to necessitate stops every fifty miles or so, we figured it was time to head home. It got worse rapidly, and we didn't dare turn off the engine for fear we couldn't get it started again. When we reached the border, Canada Customs, choking in our cloud of blue smoke, waved us through without stopping (try that today). I dropped Michael off at his house. When I got home, I turned off the engine, walked to the house, and was startled by a gigantic explosion. The exhaust system clanked onto the driveway. It was six weeks before I got the Rover going again.

There was another trip, this one with Michael, Geoff Mott, the late Barry Shepherd, and me. Sports car dreams, traveling in a couple of Triumph TR's. There are photos of us driving down the steep, wiggly Lombard Street Hill in San Francisco (you know the one). I think we did all the usual sports car roads. I think we also went to Disneyland. But nothing went wrong with the cars. One thing that did go wrong was blind dates with four girls who came from an extremely snooty Catholic girls' school up the top of Beverly Hills. I think part of the problem was logistic, since we had only four seats and the girls made eight of us. But time has drawn its magic veil over the exact circumstances—I only remember that it was an absolute disaster. I don't think we were exotic or glamorous enough.

.

I remember . . .

Courtshiр, Marriage, and Family

by Eileen Seal, Michael's wife of 43 years

My first memory of Michael was of him standing at the top of the south stairs in the old North Vancouver High School. I was standing at the bottom with Michael's sister, Helen. I was only a tenth grader, and he was a senior and at that time, only interested in cars. He showed no interest in me until I began helping with community dances that the Scout Rover Crew was sponsoring. With prodding from his sister, he finally called and asked for a date for one of the dances. On the way to the dance we had to stop at his parents' home to view the beginnings of the Tatra Special, bits of *pipe laid out on the recreation room floor waiting to be welded. We rode to the dance in Paddy's Morris Minor as Michael's driver's license had been taken away for three months due to speeding.*

Tatra Special marked with an "N" for Michael's Novice Driving Status

We dated off and on for the next five years. We became engaged while I was teaching sixth grade at Lake Cowichan on Vancouver Island. Michael was working on his B.Ed. from the University of British Columbia while teaching in Vancouver. We were married the weekend before summer school started, July 8, 1961.

Michael and Eileen Cutting Their Wedding Cake

Michael continued to teach full time while completing his degree. Next he commuted from Port Moody, B.C., to Western Washington University to earn his Master's degree. In the meantime two girls, Suzie and Lisa arrived. After the birth of Suzie, Michael hung up his racing helmet. The Tatra Special received a Chev. Engine and was raced by his friend Geoff Mott with Michael in the pit crew.

Tatra Special with Chev Engine

At the completion of Michael's Master's Degree, the Seal family sold all their cars, put their possessions in storage in their parents' basements and moved to College Station, Texas. Cathie, our third daughter was born the first year we lived in Texas. Later, in 1986, we adopted our fourth daughter, Georgia.

Left to Right—Lisa, Cathie, Eileen, Michael, & Suzie **Georgia--1990**

Michael completed his doctorate at Texas A&M University in two years and was fortunate to be hired by WWU in 1969 to teach drafting. Thus began 34 years of a job that Michael has often said he would do even if he wasn't paid.

I began to spend time at the VRI doing upholstery for the Viking Cars and later the budgeting, grant writing and general office management just so I would see my husband who was spending almost all his waking hours in the labs   Something that we both enjoy doing is sailing, and we have had five sailboats over the years ranging from an eight foot sabot to a thirty-one foot trimaran.

Manuara, Michael's and Eileen's Trimaran
With Children and Grandchildren

I remember . . .

My Dad—As Dependable and Exuberant as the Sun

by Georgia Seal

My favorite hero in life has always been my dad. No man comes even close in content of character, convictions and virtues, or work ethic. He is as dependable and exuberant as the sun. The best days of my life are those started off and finished with his pleasant and intelligent presence. As anyone who has the privilege of knowing him can attest, being acquainted with him and his brilliant mind is an honor. I am the *luckiest daughter in the world to have such an excellent and focused mentor. How could anyone ask for any more of a perfect role-model and hero?*

My dad is incredibly devoted to his research and to running the best vehicle design program possible, and this devotion is just as strong when it comes to being a quality father. When I think of all the impressive roles my dad takes on in life, I am in awe of his leadership, patience, understanding, and accomplishments. At the mere mention of his name, I am filled with appreciation, gratitude, pride, and respect. The greatest love I've ever known has been the permanent unbreakable bond between my gentle-giant, kind-hearted, teddy-bear of a father and myself. His smile warms my soul, and our discussions enrich my mind. I will always treasure our deep theological deliberations. I am acutely aware of how special my place in this world is to be included in the Seal family. No matter how uncertain and out of control the rest of the world may seem, I am always reassured by Dad's calm, rational, ever-stable demeanor. You can always expect the knowledge he is able to share to exceed your expectations. I have shared the most amazing experiences of my life with Dr. Michael Seal.

Growing up, I had so many opportunities offered to me including trips to Disneyland and Disney World, camping on the Olsen 30 (our sailboat), and sailing all the way up to Canada to visit my Grandfather. We took many road trips having to do with the Viking cars, and I have been to many marvelous museums and race-tracks. I also felt pretty special when driven to school in Dad's Stingray; I felt as if I were riding along in the bat-mobile! Dad also helped me make a scooter, and even made me my very own electric bicycle. Because of his work having to do with solar cars, I also appeared on "Bill Nye, the Science Guy." My dad's thoughtfulness made me feel very nurtured growing up as well. He contributed greatly to building up my sense of self-esteem and self-worth, and his one-of-a-kind guidance made me who I am today. I am so proud and happy to have this chance to "toot his horn." And please, dad, don't try to lose your jolly belly anymore, because the bigger you are, the more there is to hug. I love you.

I remember . . .

I'm a Seal Through and Through

by Cathie Clutter

While other little girls were playing with Barbie and jumping rope, my sisters and I were more likely to be found challenging each other to races through the halls of the old Industrial Arts building at what was then Western Washington State College. Anything with wheels could be turned into the next winner of our version of the Indianapolis 500. There were always plenty of mechanic's creepers around the automotive shop, but a tool box sitting on a dolly or an office chair spirited out of an unsuspecting professor's lab would work just as well. Although I never owned a skateboard, I found that brightly painted wooden car models were a great substitute. Looking back, I wonder if the students who worked so hard to craft scale models of their innovative automotive designs knew how we'd take them for test drives when they weren't around.

The electronic lift was another source of endless amusement. With just a push of a big green button, a loud grinding motor would slowly raise whatever I *wanted as high as I wanted. The big red button always scared me just a little. What if it didn't work? How would I explain my squashed siblings to my parents? These are things of great concern to a six year old with such immense power at her fingertips.*

But when I wasn't terrorizing my sisters or destroying the fresh coat of wax that glossed the hall floors, I remember making all sorts of sculptures out of whatever scraps I could find lying around. Anything would do: bits of fiberglass, hardened blobs of epoxy resin, and the always abundant curls of metal shavings that adorned the floor around big machines with the gigantic drill bits that could make holes the size of my head—or so it seemed to me back then.

When I was nine years old, my dad built us a go-cart which instantly propelled the Seal sisters to the status of the most popular kids in the neighborhood. Although it wasn't motorized, it was equipped with independent suspension, all-wheel brakes, and an ingenious two-passenger front/rear design. Of course the steep hill only a block away was off limits because it intercepted the busy Chuckanut Drive.

At the time I had a mad crush on a boy named Drew who lived around the corner. He was thirteen and the coolest boy that had ever talked to me. So when he asked me to ride with him when he took the first trip down that forbidden street, how could I say no? He assured me that he would be able to stop in time and I trusted him implicitly.

You might think you know where this story is going, but you don't. No – surprisingly Drew handled the go-cart masterfully. So cool was he, in fact, that he was able to maintain total control as he snaked all the way down the hill as if maneuvering through an obstacle course. Everything would have been just fine if I hadn't felt compelled to prove that I was just as cool as Drew. As I laughed and squealed with delight, I boldly unwrapped my arms from his waist to let my fingers dangle on the pavement to each side of the low riding cart as a demonstration of my fearlessness.

In the next instant my left hand got mangled in the rear axel and the rest is pretty much a blur. I'm told that I nearly lost my ring finger, which would have been ironic considering I had it in my head that I would marry Drew one day. Although I didn't end up marrying Drew, I did get to keep my finger, but not without a poignant reminder. The skin graft surgery left a patch of exposed nerve endings that, to this day, tingles with irritation from time to time.

As the years went on, Western Washington State College was officially granted university status, and the VRI continued to gain momentum and recognition. The shop was eventually moved to the new Northwest Environmental Studies Building, and as I grew older, the Viking car series multiplied in number. Each new design was sleeker and more sophisticated then the last.

By the time I entered the double digit years, the cars were being entered in all kinds of fuel economy and innovative design competitions. For the next few summers we spent our family vacations on the road traveling to all sorts of exciting places. As we drove from pit stop to pit stop in our orange Mazda RX3 station wagon, officially dubbed the "Seal Mobile," my sisters and I chatted on the CB radio to the truckers. After all, it was our job as the chase vehicle to keep suitably apprised of the speed traps (Smokey and the Bandit was big that year). Along the way we got to visit such great historical landmarks as Mount Rushmore, the Washington

Monument, the Statue of Liberty and even the Pyramids of the Sun and Moon in Mexico.

All this seemed perfectly natural to me growing up, and it wasn't until I was much older that I started to realize that not every little girl had a high tech university machine shop as her playground and spent her summer vacations on road trips with a bunch of college guys from all over the world.

But by the time I got to high school I understood both the fortunes and misfortunes of growing up as a daughter of Dr. Seal.

Not too surprisingly, I got my driver's license the day after I turned sixteen. You'd think that growing up in a house that had more exotic cars in the driveway then bedrooms that I would have been gifted with a car for my sweet sixteen. But no, unlike many of the kids at my school, that's not the way it worked in the Seal family. My parents wanted to teach us values, so we weren't handed anything on a silver platter. In retrospect, I completely respect this belief and feel that I'm a more well-rounded individual because of it—but at the time, I thought it was just plain unfair.

So, as was expected, I got an after school job and worked hard to prove how responsible I was by getting good grades and staying out of trouble. I considered it a great privilege when my parents finally allowed me to drive the afore mentioned Seal Mobile to school one day. But there were rules. I wasn't allowed to have friends in the car or go off campus at lunch time, or for that matter, go anywhere but to school and back home.

Enter Allan, mad crush boy number two. It didn't take much for Allan to cajole me into taking him and several of our friends on the McDonald's run at lunch time. Fortunately that forbidden expedition was completed without a hitch, and I was instantly propelled to the status of the most popular kid in my small group of friends. Sound familiar?

After school I agreed to drive Allan and two of his friends to their house. It was only a short distance and practically on my way home, so I didn't see the harm, especially given the success of my earlier fast food run. As we were driving down the hill I must have been awestruck by whatever fascinating things Allan was saying because the next thing I know we were slamming into the back of the car in front of us. Another car crashed into the back of us to complete the accordion effect down the line of cars. Fortunately none of us were hurt, but the Seal Mobile was crumpled from back to front.

After the trauma of making the dreaded phone call to my dad, who I knew was just up the street at the VRI, the rest is pretty much a blur. Now most teens in my situation would have been grounded or had driving privileges revoked, but not me. No, for me the punishment had to fit the crime.

It just so happened that a few years earlier Mazda Corporation had donated a silver Mazda RX3 of the same year to the VRI. Because it was a prototype, it couldn't be licensed. After removing the engine, transmission, and other good hardware there was only the shell left which wasn't of any use so it was just sitting around collecting dust awaiting its final trip to the scrap heap.

You know where this is going. Yes, for the next several weeks—maybe it was months—I trudged up to the VRI every day after school and spent every weekend working to transfer the entire engine block, transmission, etc. from the crumpled *orange body that I had destroyed to the silver Mazda. With only verbal instruction from amused engineering students, I painstakingly removed every bolt, hose, and electrical connection to the engine before lifting the block out with a crane and lowering it into its new home. So the Seal Mobile got a shiny new body and I had learned a lesson I'll never forget!*

In retrospect, I'm grateful for the unique experiences I had growing up around the VRI. And while I never took much of an interest in auto mechanics, thanks to my upbringing I was far from helpless when it came to car repair. By the time I started college, I had bought my first car, but it was more then ten years old and had seen better days. With a cordless phone tucked between my ear and shoulder and my dad on the other end of the line giving me instructions, I was able to replace the starter and fix the water pump.

Now that I can afford to pay others to fix my cars, I'm still grateful for all that I've learned from my dad. The last auto mechanic who tried to take advantage of what he perceived to be a helpless housewife ended up regretting it dearly—for I am anything but helpless when it comes to cars.

I'm a Seal through and through.

CHAPTER 2

The First Competitions & Viking Cars I, II, and III

In 1968 a group of California Institute of Technology (Cal Tech) students, led by Wally Rippel, challenged students at the Massachusetts Institute of Technology (MIT) to build an electric car to race Cal Tech's electric car across the United States. A team of MIT students, led by David Saar, accepted the challenge. The subsequent Boston-to-Pasadena race, which was won by the Cal Tech vehicle, received nationwide publicity and showed that electric vehicles have potential as a solution to motor vehicle pollution problems. Encouraged by the favorable response of other schools, students, and the public to their "Great Electric Car Race," students from MIT and Cal Tech next established the Clean Air Car Race (CACR) Organization Committee in early 1969. The Committee encouraged student teams at many schools to build vehicles to race from MIT to Cal Tech in order to publicize the air pollution problem. Seventy-five schools responded to the CACR effort, and forty competed in the actual race and pre-race testing of their cars for handling, acceleration, braking, noise, fuel economy, and emissions. The Clean Air Car Race also received extensive national and regional media coverage, which created greater public awareness of the problem of air pollution by motor vehicles.

Encouraged by public interest and by the availability of funding from sponsors in industry, government, and foundations, CACR committee members began planning another contest for early 1971. Building on their background in motor vehicle research, they tackled the problem of designing a vehicle suitable for use in the urban environment, where air pollution, noise, and safety become especially critical. Given the complexity of this problem, the organizers believed that, ultimately, only interdisciplinary efforts could be effective in solving it. But they also believed that their project was contained enough to allow a team of students, working with faculty advisors, to obtain reasonable results. The CACR committee selected engineering students representing five universities to form the steering committee for the new race, the Urban Vehicle Design Competition (UVDC). In order to assess interest in the UVDC, the CARC committee mailed questionnaires to two hundred deans of engineering. After receiving one hundred favorable responses to their questionnaire, CARC steering committee began to actively promote UVDC.

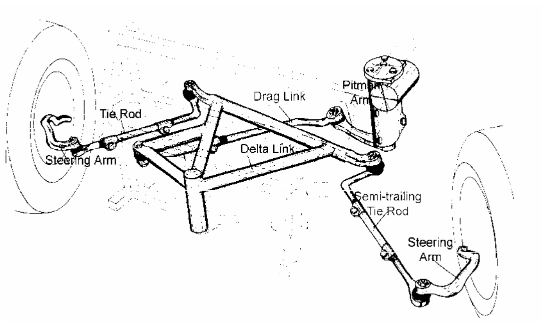
Although Western Washington State College had no engineering technology program in 1971, Western students soon heard about this urban vehicle design competition and were captivated by it. Their interest in and enthusiasm for the project would set in motion events that would give a new direction to technology research at Western and would lead eventually to the creation of the college's Vehicle Research Institute (VRI). This turn of events would also launch the career of Dr. Michael Seal and begin over three decades of exciting and innovative research in car design at Western under his inspiring leadership.

Viking I

In 1971 several of Dr. Michael Seal's Industrial Arts students heard about the earlier competitions and asked if they could design and build a vehicle to enter the UVDC. Considering that the only related course taught at this time was a power mechanics course in which students took apart Briggs and Stratton lawn mower engines, Dr. Seal thought that it would be quite a challenge to design and build a car. Never one to be daunted by a new challenge, however, Dr. Seal said "yes," and the students submitted a proposal for their design. It was accepted. The goal was to design the best vehicle for an urban setting with points being awarded for emissions, safety, consumer cost, handling, acceleration, braking, noise, turning circle, parkability, drivability, space utilization, five-mile crash, energy efficiency, and size.

The college rallied behind the effort with the Bureau for Faculty Research (BFR) contributing $3,700 matching funds, and the Industrial Technology Department gave $50. The Toyota Company donated a Toyota Corona donor car that had been damaged in shipment from Japan. Students canvassed the local community for many of the other components needed, and Viking I began to come together. By the time the car was completed, over ninety students (almost all the department's students) had participated in the project.

Viking I had a number of unique features. The steering system was designed to minimize the turning circle of the car. The turning circle radius is slightly more than the diagonal wheelbase measurement because the inside front wheel turns 87 degrees to the direction of travel. The outside front wheel takes up a position perpendicular to an axis passing through the inside rear wheel center. When the vehicle is driven, the inside wheel pivots around its tire without rotating because the inside front wheel prevents any forward or backward movement. The outside rear wheel, however, is free to drive the car due to differential action at the rear axle. As conventional steering linkage cannot provide this type of action without imposing excessive loads in the steering components when the front wheels approach lock, a novel linkage—called Extreme Ackerman Steering—was employed.

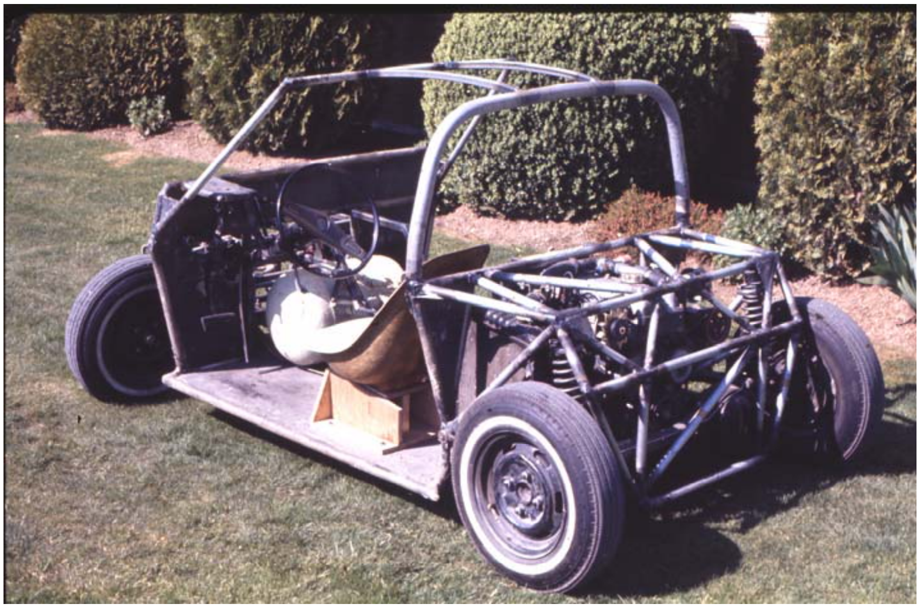


Extreme Ackerman Steering

The chassis was designed in three major sections to facilitate servicing. When seven cap screws are removed and the quick-disconnect fuel line, brake hose, and electrical plug-ins are separated, the entire engine, transmission, and drive train can be removed. Four cap screws and an electrical disconnect allow quick removal of the remaining mechanical components. The center semi-monocoque passenger bay is made from aluminum honeycomb sandwich panels faced with epoxy fiberglass. A center torque box encloses the propane fuel tank and the automatic transmission. The fixed seatback is integral to the structure as are the front and rear bulkheads. The rear space frame allows easy access to mechanical components. Full triangulation gives high torsional stiffness. The front section is very short, utilizing two lower 1½ inch diameter tubes to transmit suspension loading to the center torque box. Additional 1 inch square tubing provides mounting for the spare tire-bumper sling. The bay is not triangulated so that it can distort gradually under severe frontal collision.

Viking I Chassis

The donated 1900 cc Toyota Corona engine was converted to run on propane, and it was mounted in the rear with the drive going forward to the automatic transmission which was mounted between the seats. At that point the drive was folded and dropped with a set of Chrysler gears, which then returned along side the transmission oil pan to the beam drive axle. This engine was turbocharged with a unit from a 215 Oldsmobile V8. The exhaust turbine was stuffed with stainless steel liner to alter the A/F ratio to improve throttle response.



Viking I Engine Configuration

As far as we know, Viking I demonstrated the first example of a shoulder/lap seatbelt attached to the semi-gull wing door. The front bumper system makes use of the spare tire protruding through the front bodywork. The tire is admirably suited to absorbing the energy in a low-speed collision and will take scrapes and abrasions without damage. The rear bumper uses the energy absorbing ability of crushing steel beverage cans.

Viking I Front View

For a first effort from a non-engineering college, Viking I was a great success. Of the 66 vehicles that showed up for testing, Western's entry finished third overall, behind only the University of British Columbia and the University of Florida. Viking I won the internal combustion engine class and won the parkability award. Western was also presented with an award for innovative student engineering. In May of 1973 Viking I placed second in the Reduced Emission Device Rally (RED), which was sponsored by UCLA at Davis.

Viking I

Viking II

I remember . . .

'Dare' to Design This Car

by Craig Selvidge

During the first design phase of the Viking II, I was attending one of Dr. Seal's classes in Power Transmission. In that same classroom were about five students who were building actual scale models of a car. They would later be submitted for wind tunnel testing. My personal background was hydroplane racing and boat design. Hydroplane racing was a huge sport in the 1960s and 1970s, especially in the Seattle area. My boat designs, "Craig Craft Racing Boats," had already set numerous world speed records. I had a good understanding of aerodynamics, to say the least. That being the case, I would stop by and talk with the students who were building the models and try and give them pointers on how to make their designs better. My pointers and helpful hints were not very well received by the students building the models. I shared my concern with Dr. Seal on a few occasions, and each time he would try to get me to build and submit a model for testing. It was my *last year of school, and I was taking 18 credits a quarter, already a big load. I was also commuting to Edmonds on the weekends so I could continue to build my race boats. I had no time for extra projects. The week before the "Big Wind Tunnel Test", Russ Moye and the rest of the students had had about enough of my suggestions and prodding. It was suggested that, if I knew so much about design and aerodynamics, then I should either submit a design or keep my suggestions to myself. So I said to the students, "you furnish me with the specs and the materials to build it with, and I will build a model over the weekend." During my last class on Friday, I was met by the project leader with all materials in hand. Dr. Seal was excited that I was going to build a model but didn't think I could pull it off in the time left. It was time to put up or shut up. That weekend, I designed and built the scale model for wind tunnel testing. Monday, I showed up in class with my design. Unlike the other entries, my design was a long way from looking good. You could still see patches of bondo and fiberglass resin through the wood finish. The model still needed to be fitted for wind tunnel mounting brackets as well.*

Tuesday was the big trip south to the University of Washington to use their wind tunnel. Student by student, each model submitted was tested. I was still busy completing the mounting brackets and knew that my design would be the last one tested. The students completed their tests with their cars. Dr. Seal had also built a model to be tested, even though he knew that his design would not be used. Dr. Seal's design was 10% more efficient than the best student car design so far. Now it was my turn. The model that Dr. Seal had named the "Hydroplane" design turned in an incredible 15% more efficient results than Dr. Seal's model and 25% better than the next best student's design. I have to say as excited as I was, the other students were equally disappointed after all the time they had spent on their designs. The ride back to Bellingham was a very quiet one. Two days later, a panel of teachers from the Tech Department along with the Dean of the college chose my design, which later became the Viking II.

As a result of Dr. Seal's enthusiasm, I got involved with the project and helped loft the car for a full-scale model. Unfortunately, that was my last quarter at the college. Because of the "wind tunnel" experience, I truly believe my race boat designs improved. By 1977, Craig Craft Racing Boats were the fastest racing hydroplanes on the water. They were also credited with winning the most national championship titles as well. I have told this story often, and I owe Dr. Seal huge THANKS for helping to get me involved in this project. As an interesting side note, I saw a GM display at EPCOT Center in the early 1980s. GM had a design for the future that closely resembled the Viking II.

I remember . . .

A "Mobile Command Center" and Making Rear Hatch Hinges for Viking II

by Lionel Archdale

Since January 2001 I have been the lead instructor for the Industrial Plant Maintenance Technology program at Lake Washington Technical College in

Kirkland. Since graduating in 1976, I haven't had too much contact with anyone at the Vehicle Research Institute or WWU.

When I first met Dr. Mike Seal in 1974, I was impressed by his ability to take complex concepts or theories and simplify them. I am sure part of that impression was created by his skill at drawing the topic out perfectly as he lectured. I do not remember his using an erasure except to draw the "next frame." He was a multi-tasker before the term became popular. Out of class Dr. Seal was a mobile command center.

He asked a group of us, "Does anyone know how to operate a sewing machine?" I thought the question had something to do with the lesson. Naively, I said "yes." My mother had let me use her Singer when I was a Boy Scout. She let me sew on my own badges. I also made a lot of money in the Navy with my own portable sewing machine. Not only did I volunteer to "sew something," but I also went with Dr. Seal to his house to pick up his wife's sewing machine.

*For some reason I was driving the family car that day. It was a red 1972 AMC **Sport-about** with caning decals on the sides. It was a fancy-looking station wagon. En route to pick up the sewing machine and after some discussion about the car, Dr. Seal said: "Would you mind telling me what features persuaded you to buy this car?" I said: "Well, my wife is tall, and this is the only car we test drove that she could get into or out of without banging her knee on the steering column." He said with a chuckle, "I am sure that is one factor the design team did not have on their list."*

When we reached the Seal house, his wife, Eileen, was reluctant to "loan out" the sewing machine. After some promises, we took it back to school, brought it into the shop, and set it up. A pattern and the fabric pieces were already there and cut. It was a simple, straightforward design. I started to put it together.

So, my first assignment on the Viking II car was to sew the upholstery for the bucket seats. The seats were very similar to fiberglass chairs popular at the time. They looked like the famous Saarinen design without arms or any pedestal portion. The shape had also been custom-fitted to the interior of the car. The seats met basic function criteria without any frills. Armrests or position adjustments were not included and not part of the plan. The seats were fastened right to the deck. The front base half for Viking II was a perfectly flat section of honeycomb aluminum deck material. I think it was surplus structural material as used on some Boeing planes.

I failed to get the naugahyde pieces sewn together. I was also nervous about breaking the machine. Dr. Seal dropped by to check on the progress, and then he made a call. Mrs. Seal retrieved her machine, took the pattern and the material, and went back home. The following Monday morning, the upholstery was all sewn together and in the shop. Installation was quick. It was very awkward to get into the driver's seat. It was even difficult to get into the passenger seat. It was a tight space and no wiggle room.

I am not sure exactly when Dr Seal took Viking II for a test drive, but the body was not on it yet. Late one afternoon he fired it up and drove off. I had a friend in Campus Security who told me later they got a call that, "Some kid on a go-kart is down here ripping around the practice field." Campus Security responded and chased the violator up the road toward Old Main. When they finally cornered him, lo and behold, it was Dr. Seal just back to the shop after a test spin.

The body was not yet ready because the windshield had been custom-made in Mexico and had been delayed in shipment. It was at this point I got my next assignment. If you remember what Viking II looks like—it has two hatches. At mid-section, the front hatch lifts up and forward to gain entry to the driver-passenger compartment. The rear hatch lifts from the rear and tilts forward to access the rear-mounted engine.

The engine already had a science fiction look to it. The power plant was Subaru. The carburetion was a Dr. Seal-and-cohorts' design to provide the most economical fuel-to-air ratio at every level of rpm of the engine. It was three or four stages. In other words, it was really three or four separate carburetors. With insulation and aluminum lagging, it had an unusual look. The power plant was mostly carburetors. I had an idea of what was going on, but I was not directly involved.

In a small group we were discussing the hatches and the need for custom-built hinges. I mentioned that I had worked for a Chief Engineer at Darigold who solved similar problems by using paper cutouts. His philosophy was, "If it didn't work on paper, it would never work in the real world." We also noticed both hatches had compound curves. Extreme compound curves look like Christmas ribbon candy, which bends in two directions simultaneously. Compound curves meant the pivot points for the hinges had to change position or risk breaking off the edges of the fiberglass at the joints. The rear hatch had a reverse curve segment in the line over double hump. Dr Seal asked me if I would be interested in working up some cutout models and sketches of possible solutions.

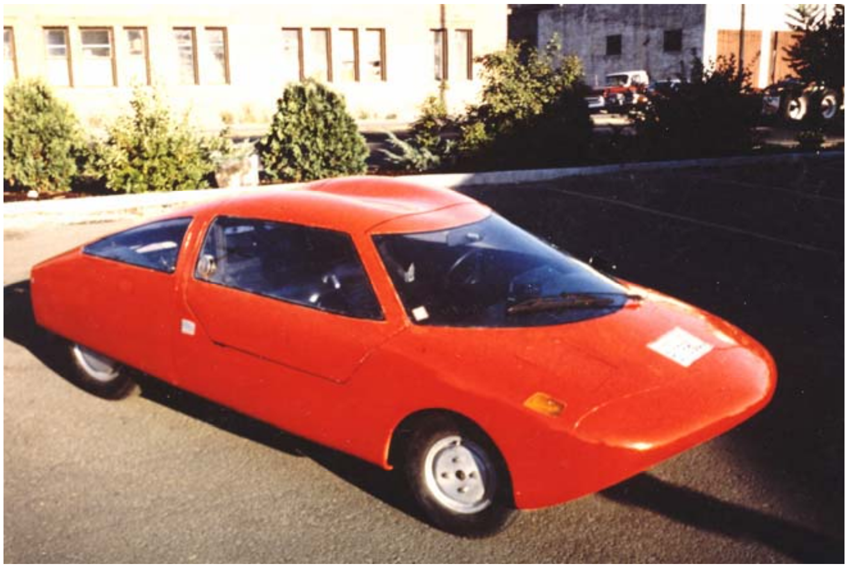
The front hatch was relatively easy. Expandable rod base plates were fabricated and mounted in the right places. The rods hold the front hatch up after it is opened. There were no reverse segments in the compound curves on the front hatch. We used some ready-made stainless steel hinges.

The rear hatch was an entirely different story. Many, many sketches and paper cutouts were made. I remember the frustration. It took several weeks and more than one prototype to meet all the criteria. The first and most important was that no damage to the lip or edges of the joint occur. Damage to the lip could affect the structural integrity of the body. Cracks and missing pieces could even impact the aerodynamics. Second and most difficult was that the hatch had to open more than 90 degrees but not fall forward. It wasn't exactly like lifting a car hood. Eventually, one hinge design showed promise. The set was made which met all the needs. I think small round stock rod was used to prop up the hatch. It actually stopped in an upright position at less than 90 degrees. There was a big sigh of relief when both hatches worked. As they say, "The rest is history!"

Personally, I always had a feeling of accomplishment. The kudos for the car, the program, and Dr. Seal seemed only natural. For many years, I have told co-workers that my claim to fame was this: "I designed and made the rear hatch hinges for a Viking car at WWU." I learned a great deal from Dr. Michael Seal—lessons in problem solving, cooperative work, and fabrication techniques that have all served me well.

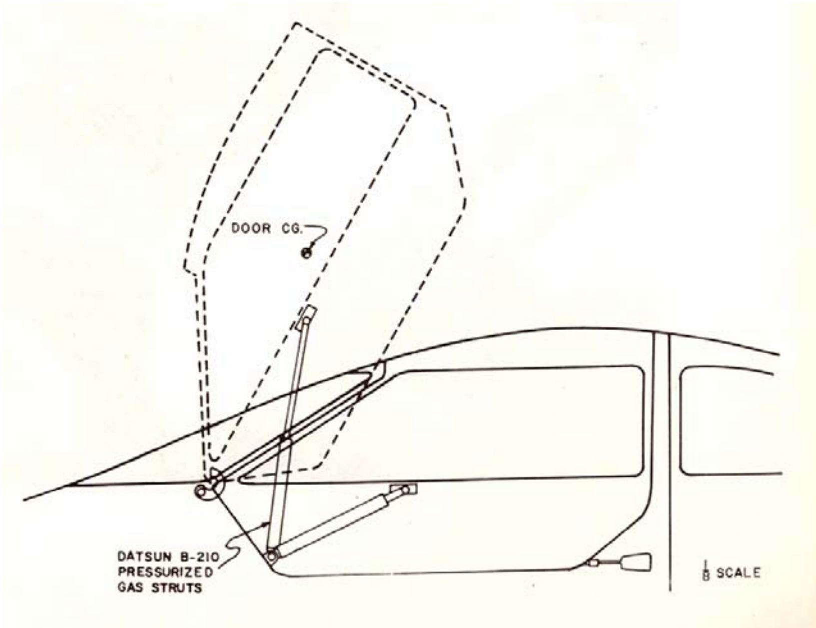
Viking II

After the success of Viking I, Dr. Seal's students started to design their second car; they used a grant of $30,000 from the Washington State Department of Energy and Transportation to build the car. Viking II was designed to compete in the 1975 Student-Engineered Economy Design Rally (SEED). This vehicle was to be an aerodynamic, lightweight, two passenger sports car that would get 60 miles to the gallon (mpg) and meet the 1977 California emission standards. Wind tunnel models of a number of designs were built and tested. The best body shape was designed by Craig Selvidge, and he and Dr. Seal received a patent for the sleek form. Utilizing an aerodynamic shape to improve fuel efficiency was not considered important in the early 1970s, so the vehicle designers for the automotive companies in Detroit had not yet introduced aerodynamic vehicles. Viking II's body is tapered in plane section which forces a crab-track configuration. The rear wheels are enclosed within the body. A double hump for occupants' heads allows minimum frontal area. All glass is fitted completely flush to improve airflow. There is no radiator opening in the front as an opening for the radiator duct is provided underneath the vehicle underpan in a high pressure area. Air is exhausted to a low pressure area at the rear of the car.



Viking II

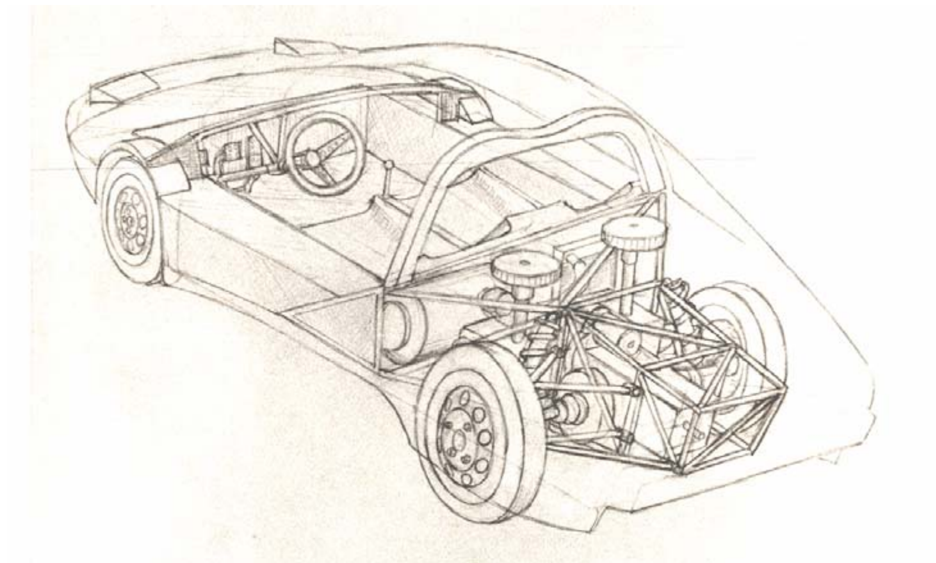
By the winter of 1974, the body plug and mold had been completed and construction of the plastic body was underway. The body has a high sill step-over height which, combined with a low overall height of the car, makes use of conventional doors impractical. A single hatch in the forward part of the roof serves as a door; it pivots upward and forward from the hinge points at the lower corners of the windshield.



Viking II Door Hatch Detail

Viking II has a soft bumper capable of withstanding 5 mph impacts. Behind this bumper and on both sides of the car are aluminum structures, 9 inches thick, which protect the occupants by deforming and absorbing impact energy from collisions from any direction at speeds up to 30 mph.

The assembled vehicle weighs 1,100 lbs. and is powered by a 1100 cc Subaru, water-cooled, four-cycle engine modified to run on propane. The single primary carburetor is mounted on a manifold ram tuned for 2800 rpm, which is the point of main fuel economy for this engine. The two secondary carburetors are mounted on manifolds ram tuned for 5500 rpm. The four-branch header system has also been tuned for this speed to fill out a low spot in the WOT (Wide Open Throttle) curve. The transmission is a four speed transaxle manufactured by Subaru. Independent suspension is used front and rear, with coil springs and tube-type shock absorbers. Steering design permits a 12 foot turning radius; the hub of the steering wheel is made of expanded metal, designed to crush under severe impact.



Michael Seal's Original Sketch of Viking II

The 1975 SEED competition, a 1,400 mile rally from Bellingham to Los Angeles, was sponsored by Western Washington State College and the University of California at Los Angeles. Eleven cars, designed by students from the United States, Canada, and Japan, competed to determine which entry had the best combination of efficiency, low pollution and handling. Performance testing was done in Bellingham and emission testing in Los Angeles. Viking II won the SEED rally with a fuel economy of 58 mpg, using propane as a fuel, and also established the lowest exhaust emissions measured in the contest.

Viking III

Viking III was a Datsun B210 loaned to Western Washington University for us to modify. The goal was to improve the fuel economy and emissions by converting to propane and reducing the weight and the aerodynamic profile. Entered in the 1976 Sea to Sea Econorally, Viking III took third place overall in the over 2000 lbs. division, with a first place in performance and third place in fuel economy. Viking III was then returned to Datsun for display at the Nissan Museum in Los Angeles.

Viking III

CHAPTER 3

Fuel Economy and Speed – Viking Cars IV and V

I remember . . .

The Establishment, Growth, and Development of the Vehicle Research Institute (VRI) at Western Washington College, later Western Washington University

by Clyde Hackler

I came to Western Washington College as Chair of the Technology Department in the fall of 1974. Before I arrived on the scene, Viking I had already been completed and had established itself as an absolutely incredible public relations gold mine. The vehicle had been exhibited in the Washington state capitol, and Governor Dan Evans had driven it for public relations purposes. Later on, Viking I traveled all the way across the country to be exhibited in the Smithsonian Institute and the Capitol Rotunda in the other Washington. It was also exhibited in virtually every Washington county fair. People wanted to see what students could do with virtually no outside funding. This point is important to remember. It became clear to me early on that, as for educational efforts, the public generally perceived that Western Washington College was capable of providing a positive educational opportunity instead of simply hosting students who were using education as a means to avoid being drafted into U.S. military service.

At that time, Viking II was under construction. Jerry Flora was in his last year as chief executive officer of Western Washington College. Paul Olscamp would take over in summer 1975. A new dean had arrived here in 1974—the same year as I—a fellow named James (Jim) Davis. Dean Davis plays an important role in a 1979 road trip, which I'll tell you about a bit later on.

As I recall, there was no serious outside funding for Viking II, but Mike and his team put together a contest and invited folks from all over the world to come see if they had a vehicle that could be high performance, maneuverable, and energy efficient, with very low emissions. Those were the criteria. That must have been in 1975.

The most exotic entry came from Japan and ran on liquid hydrogen. (Liquid hydrogen was outlawed in Japan, but schools could get small amounts for research.) Well about 20-25 advanced automotive engineering students arrived in Bellingham. Union Carbide supplied them liquid hydrogen to get from Bellingham to Los Angeles. Now this race was touted as no fuel emissions and high performance. When we learned about the liquid hydrogen, we all hid behind the Tech building! But the Japanese entrant had people watching the valves on a 24 hour cycle.

Western won that contest with Viking II. I told my son that I thought the winner would be on the 6 o'clock evening news with Walter Cronkite. However, my son and I went fishing that afternoon and didn't get back in time to see it. As it turned out, Dean Davis called me the next day to ask if I'd watched the 6:00 news. Cronkite didn't do the interview, he said; but Mr. Roger Mudd did the interview with Mike Seal. Mike, reported Dean Davis, was just as comfortable in front of that *camera as anything you could believe. The interview was 1 minute and 40-something seconds long—on the 6:00 evening news! And you don't think that made an impression on folks around this campus? Well, let me tell you, it did.*

About this time, the Vehicle Research Institute (VRI) of Western Washington College officially came into existence. Let me tell you something about why and how it became an officially established institute.

There was at that time in the mid-seventies a general public perception of Western Washington College that Mike had encountered on several occasions as he tried to raise funds. Since he represented a "state college," emerging from a teacher-training institution, prospective donors were puzzled. How and why should a technology professor be seeking funding? People believed that a teacher education institution had no capability to advance research or development of any type. That was the "why."

As to "how" the institute was founded, it came about this way. When we talked about the Viking cars, Mike said that what he needed was a letterhead that would inform rather then mislead potential agencies and organizations with research funds. If, for example, we had an institute that was serious, he thought it might make a difference. I agreed. So we went first to the department, who said go ahead and do whatever you can. In those days entrepreneurial stuff was good because Western was in financial troubles and because of the public perception of Western. Anything we could do that was positive was well received.

So Mike and I went to see Jim Albers, who was acting provost at that time. (As a side note, his son later graduated from our department.) We told him what we were trying to do. In fact, Mike had proposed to develop a transportation institute. Jim, as a physicist, was interested, kind, and considerate. But he thought a transportation institute was kind of ambitious. "What you really want to do is build cars," he said. "Would you consider calling it the 'vehicle research institute'?" "Sure," said Mike. That name suited him fine. Then the next thing I heard came from Paul Oscamp, Western's new president, who called me in to ask about this proposal for a vehicle research institute. I explained why it was needed. Olscamp asked, "Well, is this going to cost me any money?" "No, it won't cost you a dime," I replied. "We'll do all the work, and it will make you money."

"OK," said Olscamp, and he sent that recommendation on to the Board of Trustees as an information item. No discussion or anything. A man on our staff in visual communications, Gerrit Byenman, did the art work and didn't charge us anything. So in September 1975, the Vehicle Research Institute (VRI) became an official institutional unit. We got the VRI letterhead, and it did, in fact, really make a difference.

We remember . . .

Bill Brown

by Eileen and Michael Seal

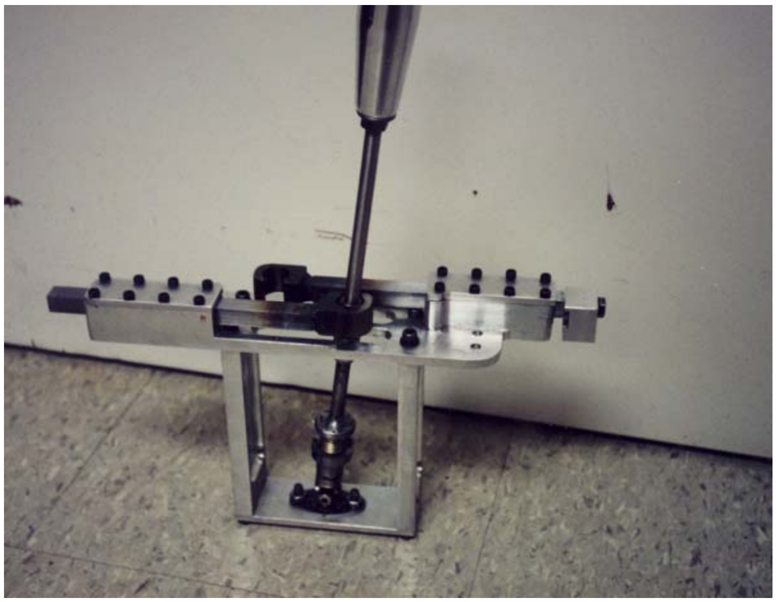
No history of the VRI would be complete without a few words about Major William J. Brown (Bill). Bill joined what later became the Engineering Technology Department first as a student assistant in 1966 while working on his degree. He later was hired as a general technician in 1968 and then as an instructional technician until his retirement in 1983. When he retired from the Engineering Technology Department, Bill became a "dollar a year man," and, at the request of the department, the university provost at the time, Dr. Talbot, gave Bill the official title of "Research Associate for the VRI."

Bill Brown was an invaluable asset to the VRI because he could machine almost anything needed by the Viking cars and the VRI. He had extraordinary problem solving abilities. He was able to find a solution to seemingly insurmountable problems in which the students and Michael found themselves. His solutions were usually ingenious and inexpensive to execute.

A World War II veteran, Bill had honed his extraordinary natural gifts in the war, where he had landed on the shores of France four days after D-Day. Bill was one of the many soldiers who had followed behind the retreating German army reconnecting the communication lines, often finding a German on the other end of the phone as he worked to reestablish the phone system for the allied troops. After the war he was stationed in Okinawa where he acquired a landing craft. He converted this vessel to a very comfortable pleasure boat which he had shipped back to the US by the army along with all the other possessions he had acquired. This boat surprised many a boater as it appeared to charge a beach, after which Bill and his passengers would climb down a ladder off the bow directly to the beach. Technology faculty enjoyed many a fishing trip with Bill and the "Billican."

Bill Machining Viking II's Rear Wheel

Bill caught the car building bug and designed and built the a car, called the B1, for himself. It was a monocoque aluminum chassis car that had a diesel engine for its power plant. The body for the car was somewhat crudely formed aluminum, as aesthetics were not Bill's prime interest. The mechanics of the vehicle were much more interesting to him. He designed and machined, out of billet aluminum, a six speed gearbox using an upside down second gear for an extreme overdrive fifth gear. The gearbox is notable in that it shifted just like Bill's Brown and Sharpe mill.



Shifter Designed and Machined for the B1 by Bill Brown

After his death Carolyn, his daughter, donated the B1, a mill, and a number of his tools to the VRI. For Bill's generous giving of his time and knowledge, a laboratory in the VRI is dedicated to him, and on the wall a plaque, containing a few of his ashes, commemorates this extraordinary man who was so vital a part of the VRI.

Vikings IV and V

The joint Washington State Legislative Highway Committee allocated $56,000 to the Vehicle Research Institute to continue research and develop two new vehicles. Viking IV employed a gasoline-fed stratified charge rotary engine to challenge the world speed record for "g" sports racing class of 157 mph at the Bonneville Salt Flats. The Western Aluminum Producers donated aluminum and a special aluminum forming machine, as well as technical expertise. Viking V was to be a more economical version of Viking !V.

The aerodynamic design practices followed by the land speed cars competing at Bonneville Salt Flats were followed in the body design of both vehicles. The rounded nose, smoothly faired greenhouse, and the long tail of the Bonneville cars were adapted for the Viking IV. The final drag coefficient was .30 for a frontal area of 1.2774 square meters. All body panels were given smooth contours, and all flow-disrupting window edges and trim were avoided. To combat lift, the bodies were given a negative rake, with ground clearance of 125 mm at front axle and 2003 mm at the back. The fast back did not exceed the 12 degree maximum used by Bonneville designers. To assure attached airflow to the rear of the cars, care was taken to reach a design that compromised the streamlining as little as possible while still meeting practical and legal requirements for a road car. To decrease frontal area and improve handling, the car's height was fixed at 42 inches, which is considered the practical minimum. The mid-engine configuration was chosen for handling and for solving the problem of forward vision over the engine in such a low car.

To simplify body construction and reduce weight, the design minimized the number of separate body parts by eliminating the doors and making a simple entrance hatch, counterbalanced by gas struts. This surprisingly practical solution removes the roof when the hatch is open, greatly easing entry into this extremely low car. To simplify construction, the pop-up headlights were combined into a solid bar of four across, mounted under the leading edge of the small front trunk lid. The lid hinges from the back and, through a simple level mechanism, raises the headlights 4 inches for night running and completely up for trunk access. No heavy servos were needed.

A search for a windshield that would best fit the car's shape found that the Opel GT was ideal if the lower corners were ground off to allow greater rake. The side windows were heated and drape-formed from scratch-resistant abrite coated polycarbonate. The 5 mph front bumper was constructed of urethane foam covered by a solid 1 mm urethane skin.

The engine cooling is accomplished by a NACA duct placed in the console between the passengers and channeling air from beneath the car to an aluminum radiator placed behind the occupants and just in front of the engine. The air then exits out louvers behind the rear window. At first an electric fan was needed, but when the louvers were discovered to be constrictive and subsequently enlarged, a fan became unnecessary. This arrangement removes the need for drag-inducing openings in the front bumper and prevents problems with rocks and dirt in the radiator, which is only 7 inches above the road.

Aluminum Bodied Viking IV

In order to provide the lightest possible weight for Viking IV, the body and chassis were constructed entirely from aluminum. The body is 3003 aluminum alloy. Its construction was greatly simplified by the use of a wheeling machine for hand-forming the compound curves. Finishing of panels and flanging was done with hammer and dolly. The panels were welded together with a TIG torch. This operation was difficult because warping had to be avoided. Access to the engine compartment was provided by hinging the entire rear body backwards at the rear of the chassis.

The chassis is a monocoque constructed of flat, riveted panels of 2024 aluminum alloy heat-treated to T6. Two major torque boxes provide strength along the sides of the car. These impact deformable boxes rise to 20 inches, providing side crash protection as they are completely filled with aluminum honeycomb. This form of chassis is surprisingly simple to build and extremely light at 110 lbs.

For best handling, the suspension was modeled after Formula 1 racing cars. Light, unequal length “A” arms of 4130 steel tubing are hinged to the chassis with bronze bushed spherical rod ends. Springing is by coil over shock units. In front, Fiat 124 spindles are used, combined with a Subaru rack and pinion. In the rear aluminum hub, carriers were cast from 356 alloy with 2% strontium and heat-treated to T6.

Fiat 124 four-wheel disk brakes were fitted in the front. The rear disks are Subaru. Light aluminum pedals welded from sheet stock are coupled via a bias bar to dual master cylinders. The light weight of the car makes power brakes and steering unnecessary. Steering is so light that it actually feels power assisted. Turning circle curb to curb is 10 meters. Wheels are of stamped aluminum construction, riveted together. To allow minimum body height in front, 165/70-13 tires were used. For maximum gear ratio and to provide body rake for lift avoidance, 185/70-15 tires were used on the rear. Tires were CN36 Pirelli’s VR rated. Tire width choice was a compromise between handling and rolling drag.

In order to test the car's high speed handling and confirm the drag numbers seen in the wind tunnel, it was decided to run the car at the Bonneville Salt Flats in the summer of 1977. The car was equipped with a roll bar, an FE-1301 Halon fire system, and a five-point racing harness. To reach high speed an engine of high power to weight ratio was needed. The Mazda rotary was chosen because of its high redline and the ease with which its power can be increased. To meet engine class restrictions, the older l0A R-100 of 982 cc (60 cubic inches) was used. This engine was bridgeported, a technique in which the main intake port in the engine is enlarged and a second, smaller port cut, leaving a "bridge" in between upon which an important rotor seal can ride. The engine was then fitted with a free-flowing intake manifold and a 600 cfm four-barrel carburetor. In stock form, the Mazda l0A produces 80 bhp. Bridgeported, it produces 175 bhp. Unfortunately, difficulties were encountered at the track with the lubrication of the rotor bearings brought on by the lack of a crankshaft-mounted spray lube system on the early l0A engine. However, many runs were made with a completely stock 90 bhp 12A RX3 engine. A speed of 141.73 mph was achieved. High speed handling was found to be excellent, ending fears of lift and instability caused by the unusual shape.

Viking IV on Bonneville Salt Flats

In 1978 it was decided to modify the advanced and larger 13B RX4 rotary engine for performance. Rather than use bridgeports, we decided to use peripheral ports. Here, the intake ports were changed from the side housings to the epitrochoidal housing above the existing exhaust ports. The old side ports were filled with epoxy and a large aluminum plug that was shrunk into a hole bored through the water jacket of the rotor housing. The new intake port was milled through the plug. This modification, coupled with a large 48 1DA Weber two-barrel carburetor with 45 mm venturies, raised power from 110 bhp to a surprising 275 bhp. The completed engine started easily and had good idle and full range torque.

When cooling problems caused engine damage, successful top speed runs again eluded us. Still, 166.97 mph (268.71 kph) was reached, and drivability was again excellent.

As Viking IV's high speed handling and stability had been proved with the performance rotary engines, it was time for conversion to a roadworthy and comfortable street car. The best mileage produced with a rotary was 33 mpg (7.128 litres/100 km) with the 141 mph (228 kph) 12A engine. While performance was spectacular, this mileage was insufficient for our concept of an economy sports car.

In search of greater economy, an l0A engine was converted from twin to single rotor configuration. This conversion involved grinding the second lobe off the crankshaft and relocating the main bearing where the second rotor bearing had been. The engine was assembled with only two end plates and single rotor housing, shortening and lightening it considerably. This 491 cc single rotor produced 40 bhp and a returned fuel economy of 55 mpg at 55 mph (4.276 litres/100 km @ 88.5 kph). The reduced displacement limited low end torque. While completely drivable, the single rotor engine car was decidedly slow on acceleration.

Economy Competitions

In the summer of 1979, Viking IV competed in the Energy Efficient Vehicle Contest at G.M. Proving Grounds in Milford, Michigan. It was accompanied by its just completed near twin, Viking V and by the older Viking II. Viking IV and Viking II were driven to the competition; Viking V was carried to North Dakota in the support truck, “Sasquatch,” and then was driven the rest of the way. Viking IV achieved the highest mileage of the meet, 90.30 mpg and received the best marks in acceleration and handling. Also, it passed the 1980 emission requirements. In the final awards, Viking IV ranked third overall, having been accessed penalties because it was just a two-seater with limited carrying capacity.

I remember . . .

Our 1979 Trip to Michigan—
The Journey of the "Sasquatch" and Viking V

by Clyde Hackler

This story recounts some of the events of the only long road trip I ever took with the VRI team and the Viking cars. We went to Detroit in the summer of 1979 for the energy efficient vehicle competition. (Well, actually, it was Milford, Michigan.) I would ride to the competition with the team and then fly on to Virginia Polytechnic Institute (VPI) where I had some business in late August. For me, the road trip was a very interesting experience. All the others were accustomed to this kind of stuff, but for me it was an absolutely remarkable experience—and a very positive one.

The trials would be held at the General Motors proving grounds, August 13-17. We were set to leave on Sunday, August 6. President Olscamp had arranged a big send-off publicity affair. He had some things to say. We were there all packed and ready to leave. We were going to drive two of the vehicles that would be in the contest and also a support vehicle that we dubbed the "Sasquatch"—a Ford cab-over truck that, on previous trips, had broken down on every road in this country. In the back of the truck, we had special tools, student clothes and suitcases, and Viking V, equipped with Bill Brown's B1 diesel engine.

Now the B1 engine plays an important role in this story. The B1 was a vehicle designed and built by Bill Brown, who was still a lab technician at that time. He had found a very small stationary diesel engine, designed to be a power source for pumps or generators. The engine was never designed to be put in a vehicle. But Bill had worked on it on his own time, and now it would be used to power Viking V in the contest. But Viking V and its B1 engine were being carried to the contest in Michigan in the back of that Bigfoot truck.

So, after the fanfare, we were ready to leave. Bill, Mike, and I were going to ride in the Sasquatch, and it just happened that I was to be the first driver. Well, I couldn't get the truck into gear. And Russ Moye, a graduate assistant attached to the VRI, came over and said, "Hold on just a minute." He used a dip stick and checked the clutching mechanism. Then he went away and came back with a bottle of stuff and poured it in there. Said, "try it now." So I did, and it went. Hmmm.

Let me stop a minute and identify some of the student members of this group. Bruce Lee took his degree and went to Alaska, last I heard. Bill Green—he took a degree in Industrial Design, and he just wouldn't leave. So we got some kind of assistantship for him. He got billed as "Bondo Bill Green," because he liked to spread bondo so well, and he was good at it. Well, he finally did leave and went to California, got a Master's in architecture, and now is director of Industrial Design at VPI. Russ Moye didn't go on that trip. Jim Nelson became an Industrial Arts teacher and has had a successful career in the Ferndale school district. Larry Graff, after graduation, went into boating and is now CEO of one of the biggest pleasure boat building companies in this part of the country. Craig Henderson is now his own boss and builds boats; some are sea worthy, but most are for inland waters. There was another guy that we all thought a lot of, Cole Dalton. And a photographer from *here in town, but I can't remember his name. And there may have been others whose names I can't remember at the moment.*

But I want to say, also, that over the years, the opportunities to students associated with these kinds of projects helped to achieve objectives in all of the three principal domains of education: cognitive, psychomotor, and, truly, the affective domain—that's the one that public education has done least with. I can see how such projects contribute to student growth and development in so many important ways.

Now for the trip itself. Day 1, Bellingham to Seattle, was uneventful. We had a press conference at Seattle Center and then headed east on Interstate 90. The students in their respective vehicles outpaced us. I don't know where they were, but they weren't behind us. I was driving. Then, as we were going down the hill approaching Ellensburg, in that big, long straightaway, no traffic at all, I looked out ahead. "Oh, look out, fellows! We've got a problem here," I said. "Someone's had a serious accident." As we got closer, Mike said, "Good grief! That's one of our people!" It was Bill Green and Bruce Lee, I think; I'm not sure. By the time we got there, they were both out of the car and standing up. What had happened was they had worked so long and so hard getting ready for this trip, they were just exhausted. The driver just fell asleep. Well, as luck would have it, both had fallen asleep. That probably saved their lives. The car was destroyed, but they were safe. We were so relieved there no serious injuries. That delayed the trip, of course, because we had to make arrangement to get Lee's car, I think it was, to a garage in Ellensburg. So we must all five have ridden in the cab of the truck on to Spokane. The transmission in Sasquatch was acting badly. I couldn't drive it. So Mike took over; he knew how to rev it up, and release it, and goose it, get it in and out of gear. We got into Spokane (the target for the first night) about midnight and spent the night there. That was the first day.

Day 2. We must have corrected the gear shifting problem, maybe more fluid, and then we headed out. Somewhere in northern Idaho around Kellogg, where the interstate was not complete, we found ourselves on a two-lane road, a good road but not a state road. There the truck just went billywonkers; it started to rattle and shake. I couldn't do anything with it. We pulled off the road, popped the hood, and realized that there was an ignition problem of some sort. Bill concluded that one of the weights on the distributor had broken off and gone somewhere; it had three. Well, Bill got out his toolbox and started to work on the carburetor. Mike said, "That's not our problem." Bill said it could be a problem because it was leaking gasoline all over everything. "I'm going to fix that before anything else." And he did. Then Mike and Bill caucused a bit and said we had three weights on there. "We'll take the weight off 180 degrees from the one that came off. That will leave us two. But we'll have to build a shear pin." They caucused again on how to do it. Then Bill just walked around and picked up two files. He took one file and started filing on the tang of the other file. I said, "What are you doing?" "I'm building the shear pin we have to put in there," Bill replied. Sure enough, he rigged it up. Well, to make a long story short, after all that, we were back on the road in less than one hour. I know because I timed it. I was thoroughly impressed.

But the truck was still not running good. Up to 0-15 or 20 mph, you really had to goose it. After that, from 25-50, it would run pretty good. The students were out on the road way ahead of us. We were so far behind that it won't work for me to continue to separate the events into days 1,2,3, etc. In fact, we were driving at night and still not out on the Montana plains. I mean we were still driving in rough terrain, hillsides, and so on. We pulled into a camping, trailer park site about 3:00 in the morning and just crawled under the truck and took a nap for two to three hours. Somewhere along the line, the students realized they were too far ahead of us and stopped to wait. The next morning we met up with them somewhere in Montana because when we got over the mountains, we decided we had to do something about the truck. It was pretty barren territory there. But Mike saw a sign for a service station. We pulled off on to a dirt road to find it. Bill Brown stayed in the truck to keep it running, while we went in to phone to the Ford dealer in the next town. It turned out that the phone that we wanted to call from was in a cowboy bar, a mobile home turned into a bar—and nothing else. I don't know where the cowboys came from; I didn't see any horses or trucks anywhere. But when we walked in there mid-afternoon, everyone turned around and gave us a look, like "what are you people doing here?" I told Mike I thought we could probably get into a pretty good fight, but he didn't think that was a good idea. Instead, Mike asked permission to use the telephone. Sure enough, the Ford garage had the distributor. So we made arrangements to get it, but were afraid we couldn't get there before they closed. So when we came upon some of the students waiting by the side of road, Mike peeled out his roll of money, handed some of it to Larry Graff, and told him to get into the next town fast and get that distributor before they closed. And keep the receipt! It was an interesting way to do business.

Well, Larry took off. At this point, these days become blurred. We got into town, put in the new distributor in a parking lot somewhere, and headed on east. No events of significance occurred until Butte, Montana. By this time, for some reason, some of the students were behind us. Some were with us. Earlier, when we had repaired the truck, we had agreed that we would assemble again in Butte. We had little walkie-talkies, with a range of two or three miles, so we pulled off into a shopping center at Butte to wait for the rest of group to catch up with us. In a while, they arrived, and we got out to decide on a restaurant where we could have dinner. It was mid afternoon. Now, this is a true story.

As we were deciding where to go eat, the sheriff and three or four of his deputies drove up in a big station wagon, an official piece of equipment. The sheriff got out, walked up, and said "Who's in charge?" We directed him to Mike Seal. The sheriff walked over and said to Mike, "Get out of town!" Mike said "say what?" The sheriff said, "Get this bunch out of town." Bill and I were standing next to Mike. The sheriff and his deputies were all armed to the teeth, and it became clear that the sheriff wasn't joking. But Mike was beginning to get kind of obstinate. "Why are you telling us to leave town; we've done nothing," he said.

To this day I don't know what provoked the sheriff. Well, I can guess. We did look pretty seedy, students included. The students had beards and long hair and were dressed pretty ragged. We all were. I calmed Mike down and said "Come on, Mike, let's get on out of here and not cause a fuss." That sheriff was adamant about *our leaving. And by the way, some years later, we told that story to Kathy Kitto, who's from Butte. She said, "Yes, I knew that old boy, and he was a hard-nosed dude, a strange kind of a person."*

So we literally got run out of Butte, Montana. I ran up to the grocery store and grabbed some groceries, chips, etc., whatever I could get fast. And we all got on the road. That was a pretty interesting experience in itself.

In eastern Montana, we assembled and, sticking pretty close together by then, we pulled off into a parking lot and had some lunch. There were some restaurants there. We concluded that, with the speed we could make in the Sasquatch, there was no way we could get to Milford before August 13. If the students stayed with us, then we would all be late. We didn't have anything essential in the back except Viking V. So we peeled out the map, told the students here we are, and here's where we want you to go. Mike said, "You have the best chance of getting there on time." So the students headed on out. They had two of the contest cars and several others. We said, "We'll see you when we get there." I said to Mike wouldn't it be appropriate to designate a leader, so that if any disagreement came up, the leader could make a decision, for legal matters or whatever. I think Mike designated Bill Green as the leader, so they took right on off. We proceeded across North Dakota. That night, in the middle of the state—Jamestown on Interstate 90—Mike, Bill, and I, and some students who were still with us all had dinner. This may sound odd, but the only motel we'd been in up to that point was in Spokane. I don't remember if Mike gave the students money for a motel or if they even stayed in motel. We were all pretty tired.

Anyway, we had dinner in Jamestown and left about 10:30 that night. It was a beautiful night, the moon was shining, and Mike was driving. We got about twenty miles east of Jamestown, and Mike said. "It's quit." Just like that. He threw up his hands: "It's done for, it's quit." So he pulled off the side of the road, and he and Bill made a quick diagnosis. They concluded (I think it had to do with that distributor system) that it was not possible to repair the Sasquatch on the road. The engine had to be pulled out anyway. So I said, "Hey, I get the cab." Mike and Bill said "ok." So they crawled in the back of the truck, through the side door, and under the Viking V. We would all try to get some sleep, and figure out in the morning what to do.

I heard them knocking and kicking around. Then I heard one of them say, "What is this sticky stuff?" Bill said, "Don't you remember that quart of oil we opened up this morning and failed to put in a secure container?" So they bedded down in sleeping bags. At 4:00 in the morning, Mike got up and announced that there was a storm coming, and we needed to get out of there.

Now, the plan was to unload Viking V out of the truck on a ramp that we had never assembled. The students had always done that before. Also, we had to take out all the luggage to get the car out. So we didn't set up the ramp properly, but we were ready to lower the vehicle, with a winch, on to the ramp. I thought sure it would fall. But we did get the Viking on to the ground just as it was getting daylight. At that point we discovered that Bill had driven Viking V from Bellingham to Seattle, put it on the truck, but hadn't put any more fuel in it. The fuel tank was empty.

There we were: a disabled truck, a car with an empty fuel tank, and a plan. The plan was that Mike and Bill would get some fuel, get in Viking V, and head for

Milford. I would hitchhike back into Jamestown to make arrangements for Sasquatch. I would get the Ford people to come get the truck; I would rent a car, transfer the students' clothes, luggage, and special tools from Sasquatch to the rental car; and then I would catch up with Mike and Bill. First, we flagged down a big transfer truck and asked the driver if he had any diesel fuel. The truck driver was so intrigued by that little bitty diesel engine that he was thrilled to help us. So Mike and Bill got fuel from him, filled Viking V, and headed east. I walked across the freeway, and the first car I flagged stopped. It was Sunday, and, in town, I learned that the Ford garage people were having their annual picnic. So I arranged for an Oldsmobile 98 rental car (brand new) and located the picnickers, who agreed to come out and tow the truck into town. I told them they had to get it fixed. As luck would have it (and this is an important part), Jamestown, North Dakota, was the hometown of our Dean, Jim Davis. Boy, did that help us out!

The next morning, Monday, I called Eileen in Bellingham. She was coordinating the entire event because she was the only stable source of information that we had. If anyone needed information regarding any other part of the group, he called Eileen. She stayed within a short distance of the telephone, even on their return home leg of the trip. So I called, told her what had happened, and said I'd try to overtake Bill and Mike, who had more than a 24 hour lead on me. I thought I could catch them in the new car, even though it was loaded pretty heavily, filled to the brim with clothes, and luggage, and tools.

Meanwhile, the Viking V had trouble; it had gone no more than 150 miles before the rear axle went belly up. Mike and Bill found an old-time garage where the owner had a lathe and some scrap steel. He was so intrigued with the car that he told Mike and Bill, "If you guys know what you're doing, we'll get over here and remake this axle and weld it up." So that's what they did: rebuilt the rear axle in that old garage. I called two or three times a day to Eileen to find out where they were. It happened that they were off the road when I went past them, somewhere maybe in Minnesota or Wisconsin. So Eileen told me I was in front now. I drove straight through from North Dakota to Chicago. I told Eileen I'd get a hotel room in Chicago, off the south bypass, and then call her back with the address, and she could direct Mike and Bill there to the room. So that's what I did when I got into Chicago around 10:00 that night.

Apparently during their travel, Bill and Mike had to liberate an air hose, so they could siphon some fuel out of a willing trucker's tank to fill up their tank again. Bill concluded that they might need this rubber tube again, so he coiled it up and laid it on the tire that's on top of the engine; it was a rear engine mount. As luck would have it, the car got a short somewhere, just on the freeway in Chicago. The car caught on fire; fuel leaking from that coiled hose caught on fire. Mike was driving and realized what was happening because their battery was running down; the lights were getting dimmer and dimmer. But then they started getting brighter and brighter, and Mike realized it was from a fire in the back of the vehicle. They pulled off and popped the hatch. Mike started running, but Bill yelled, "It's a diesel, it won't explode." So they got the burning hose out of the vehicle and used pieces of it as a light to see if there was any damage to the car. Anyway, it was 3:00 in the morning when Mike pounded on my door and came in saying, "You wouldn't believe what *we've been through." They were both sooty black, looked like they had been mining coal for years and never taken a bath. They were absolutely black all the way around. Well, they showered and slept for about 1 ½ hours. We were already 1 ½ days late for the trials.*

But when we got outside the next morning, the battery was dead on Viking V. We thought we could compression start it by pushing it, though that's a little uncommon in a diesel rig. Anyway, Mike got in the driver's seat. And Bill and I were pushing the car around the parking lot, but it wouldn't start. Mike said, "Let's just forget the whole thing." But Bill looked at him and said, "Mike, we're going to get this vehicle to Detroit if we have to push it every step of the way. Get back in there and give it one more try." Sure enough, as you might have guessed, Viking V started up on the next try. Bill hopped in, I jumped in the Olds, and we then made it uneventfully into Milford, Michigan.

We arrived Tuesday, two days into the events. The students were doing just exactly what needed to be done. When we found the tent to sign in, we met a fellow by the name of John Sununu. (Not long after that, John H. Sununu would become the governor of New Hampshire and then White House Chief of Staff for President H. W. Bush.) Sununu, an engineering graduate of MIT—the school that was funding the competition—was there to register entrants. So when we walked into the tent, Sununu asked Mike for the payment needed to enter into the event. Although it was part of a project that MIT had funded, they still had to have an entry fee of some sort. Mike wheeled out a wad of money and asked how much. Sununu said, "There's no way we can take money. Didn't you read the regulations and see that we have to have a certified check from your institution?" And then was one of the two times in my life that I've seen Mike Seal become angry—and I mean angry. And Mike said . . . . Oh brother! Well, Bill and I both thought he and Sununu were going to get into a fight. But Sununu finally agreed to take the money, even though he kept insisting that he had no way to handle cash. Mike thought that was odd. But, anyway, they reconciled their differences.

On the ground, the students were having a very good experience. They were not exactly following all the rules, they were pushing the envelope just a bit, but it was a reasonable thing to do. GM required that we keep our support vehicles back about a mile and a half from where the trials were being held. The ground in between was simply a lawn that went down a little valley. We could see each other and talk. If someone needed a special tool, he'd just call for it, and a student would simply run across the lawn and get one. The guards were giving us trouble because no one was supposed to walk across those grounds. If we needed something, we were supposed to wait for a GM mini-bus and run our errand in that. But it was a good experience, I can tell you. I stayed with them until the last day of the contest. Jim Nelson drove me to the Detroit airport, and I flew east to keep my appointment at VPI.

The team didn't have as much trouble on the trip back home except when they got back to Jamestown, North Dakota. The truck had been repaired—ostensibly—and Craig Henderson was driving it. But, as it turned out, the truck would eat its own radiator. The fan blade was twisted in such a way that it would just eat the radiator up. The long and short of it is that from the day Craig left from

Bellingham that first Sunday in August until the time he got home again was six weeks. He was the last one home. He had to stay in Montana until a radiator could be sent up from who knows where.

Again, Dean Jim Davis was very, very helpful. From his discretionary funding, he paid all the phone bills, the costs associated with pulling out the truck engine and putting it back, the cost of sending a radiator up, and the entire hotel and food costs for Craig Henderson.

All in all, it was a good experience.

I remember . . .

A Memorable Interlude to a Year of Study at the VRI—
the 1979 Trip to Detroit (another version)

by Cole Dalton

I remember a trip to Detroit in the summer of 1979. There were a dozen or so of us "techies" headed back to the GM proving grounds for a student competition on energy efficient vehicles. I'm not sure how I even got to go on the trip. Probably just luck. I hadn't really contributed much to the projects, but I did happen to get my thumb stuck in the custom collapsible steering column of Viking IV as it was leaving, so maybe there was no choice.

Most schools were shipping their hastily built "lab queens" back to the competition in auto haulers and moving vans. We were driving our hastily built lab queens. And, sometimes, hastily driving our lab queens—our cars were fast! We had an old Ford cab-over truck we called "Sasquatch" as a support vehicle, which was stuffed with the noble Bill Brown's mobile machine shop, and I think Viking V, which was being completed as we drove! We also had a bunch of students stuffed into a VW rabbit and an old station wagon. Viking II and Viking IV (I think) were on the road.

The adventures of that trip could make a pretty good movie (comedy). We were identified as "aliens in UFO's" and run out of town by the sheriff of Butte, Montana, where we had merely stopped for food and gas. (I think Jack Bouche tried to pick up his daughter, or something.) Sasquatch broke down numerous times and was fixed, in inimitable Bill Brown style, in the middle of nowhere, with nothing. I heard later that he and Dr. Seal welded a broken distributor shaft back together with the juice from the battery!

We encountered lots of repaving projects along the way, where, in order to save our custom windshields, we were compelled to throw our coats over the glass and steer with our heads out the hatch. And, of course, we got lost a lot.

We were constantly asked by passersby, "Is it electric?" This question, at the time, was a hoot, but now it doesn't seem that funny, considering the hybrid car projects, etc. The only electric vehicles that really worked in 1979 were golf carts and fork lifts.

When we finally arrived, we were missing only a few students, and the Viking cars were still working, mostly. Despite our rag-tag group of techies, and our road-weary equipment, we ended up doing really well at the competition. But not being a *real engineering school (at the time) kept us from taking absolutely everything from the more prestigious schools with their graphs and charts showing why their non-functional concept cars were really noteworthy. I think we really shook up the old guard at GM, too. There were a lot of men in black coats taking pictures and sneaking around.*

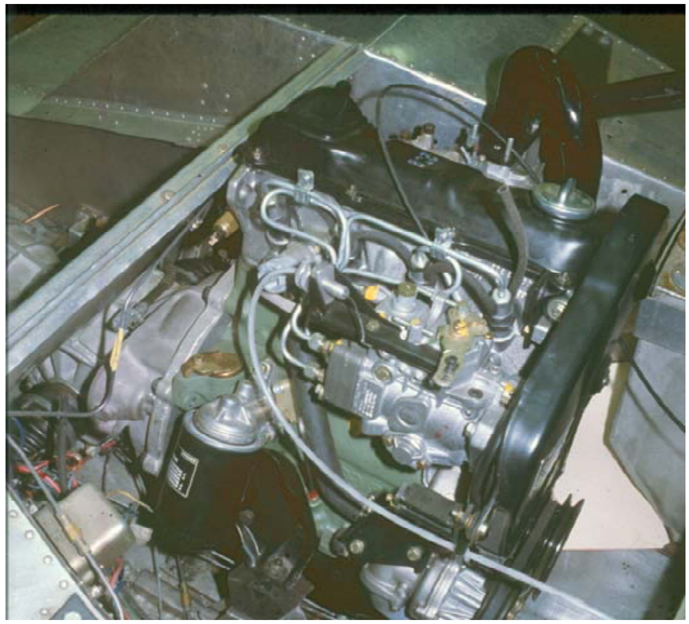
We were definitely the underdog school, but in so being, I think all of us really banded together, sort of a pre-Robert Bly "male bonding"—without the drums or hugging. A number of us have actually kept in touch over the years, so I think there may be some who can corroborate my stories. To cap off the event, we all attended the awards ceremony and dinner. And, who do you think was the keynote speaker? Senator Bob Dole.

And, throughout the entire adventure, there was Dr. Seal, calmly responding to every urgent situation, the very definition of patience and dignity. It takes a certain kind of person to take a motley crew like that and prevail.

A few years later, Dr. Seal and his wife, Eileen, were honored guests at our wedding; their presence truly honored my wife and me. We have a special place in our hearts for them, and although we only occasionally have an opportunity to visit Bellingham, we always make a point to stop in at the VRI and say "hello." I'm always surprised to be recognized, but it is as though no time has passed between us, and we are always welcomed. We have even had the chance to introduce our children to Dr. Seal. I'm only sorry they won't be able to take classes from him. I knew we should have started our family sooner

Vikings IV and V—Search for Greater Economy

After the 1979 competitions, the search was then started for an engine with sufficient performance to retain the sporting nature of Viking IV and yet achieve greater economy. The solution was found in the 48 bhp, 1471 cc Volkswagen Dasher diesel. This engine had already established a name for its economy. With the light weight and aerodynamic body of the Viking, we could also have generous acceleration, especially since we planned to turbocharge the engine. The turbo selected was a Rajay B-22, sized to boost mostly at high rpm to keep from hurting economy at freeway cruise. The compressor was piped directly to the intake manifold, no waste gate being needed. Exhaust went into an Audi diesel muffler enclosed inside the rear monocoque with only the tip of the tailpipe exposed to outside airflow. The internals of the engine and the injector pump were left unmodified.



Viking IV's Volkswagen Dasher

For the performance runs, the transmission used had been a Volkswagen Beetle four speed, suitably strengthened for the greater horsepower of the rotary engines. For increased mileage, this transmission was converted to a five speed with an ultra-high fifth gear ratio. The gear shafts and shifting fork shafts were lengthened. An after-market 1.48 to 1 ratio third gear was installed backwards as fifth, giving .676 to 1. To cover these new gears, which were now outside the normal gear case, special aluminum housing was cast. The final drive ratio in fifth gear was 2.76 to 1. This ratio proved excellent for freeway travel with the engine turning 1900 rpm at 55 mph (88 km).

The interior of the car, which had a spartan, race car look, was given comfortable upholstery and seats. Full instrumentation was added, including an airspeed indicator with a Pitot tube that retracted into the bumper for parking.

The tires were changed to Michelin XZX radials of 145 SR13 front and 165 SR15 rear. These were narrower than the Pirellis, but handling was still excellent. For minimum rolling resistance, the tires are run at +50 psi. This may seem drastic in view of their 36 psi rating, but we have never had any reliability problems.

For increased safety, the car was fitted with passive seat belts and knee bar. Inertia reels were placed in the center console, leading directly to attachment points on the latch. When the hatch is lowered, the belts drop across the chests of the occupants and latch onto steel pins attached to the roll bar. This arrangement is extremely convenient and comfortable.

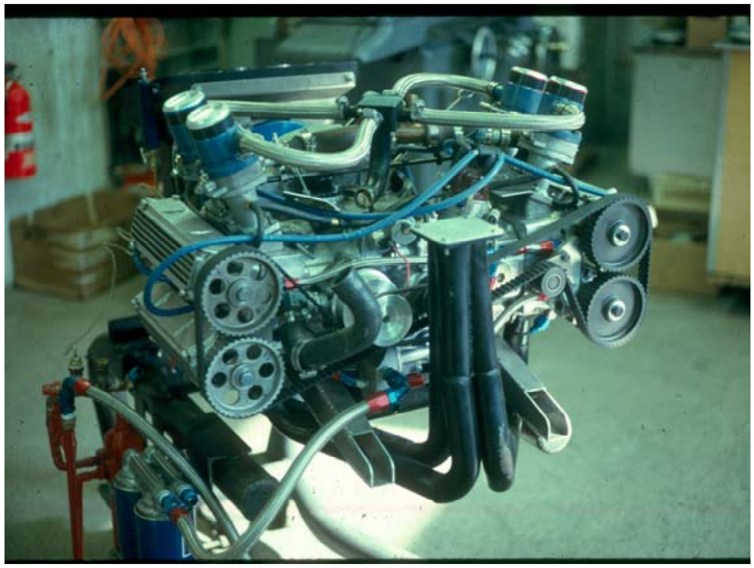
The steering column was equipped with a crushable basket made from expanded steel, which gives it an advantage over telescoping steering columns. This steering column will give when hit from any direction, yet it has proved sufficiently rigid in normal use.

The FE 1301 fire system was retained for the street after being equipped with a remote firing button so the bottle could be placed out of the passenger compartment.

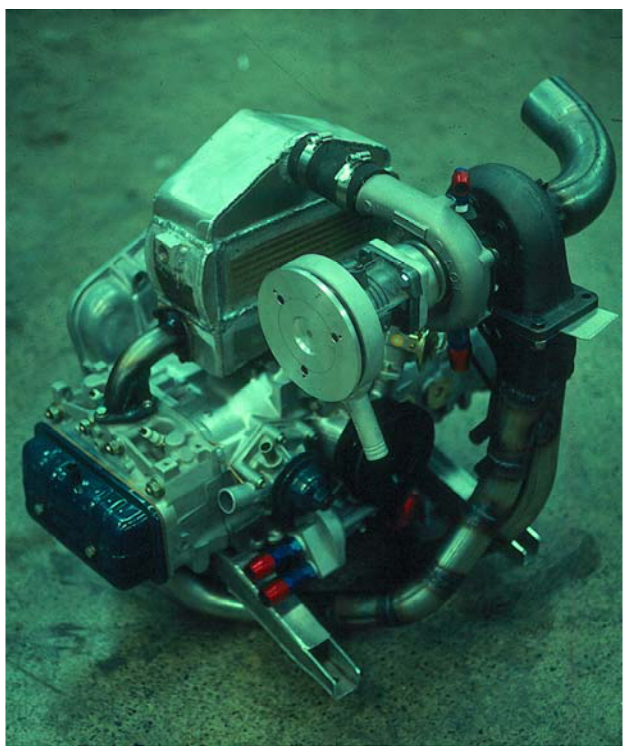
The completed street version of Viking IV weighs 1390 lbs. (630.5 kilos). It was decided that, to determine effectively the car's new performance, it would again be run at the salt flats. This time, however, the car was driven to Utah from Washington state—the first time a Bonneville Streamliner had ever been driven to the race track. It achieved a top speed of 110.071 mph. Though not as fast as the car had run in the past, this speed is respectable for a small sports car and surprising for a small diesel.

Viking IV at Bonneville with the Turbo Subaru running on CNG

Viking V is a lightweight version of Viking IV, using a fiberglass aerodynamic shell in place of the aluminum one on Viking IV. Viking V has been fitted with a variety of engines and drive trains in the last few years, including a Subaru diesel engine built at the VRI, an Isuzu two-cylinder 800 cc diesel, a 16 valve Subaru with Lotus Jensen heads, a Honda 50 cc single, and a 2 cyl/4 cyl Subaru. (In this form the car could run with five different displacements, a turbocharged, intercooled natural gas four-cylinder Subaru, which set a record at Bonneville Salt Flats for methane fuel, and a 6, 2400 cc Mercury outboard power head mounted up to a Subaru five speed transaxle.)



Viking V's Subaru 16 valve with Jensen heads running on CNG



Viking V's Turbocharged 4-Cylinder Natural Gas Engine

Viking V with Mercury Outboard Conversion

Viking V's Mercury Outboard Conversion

Viking V always remained in the shadow of Viking IV. Eventually, Viking V was taken apart, and the parts were used in the construction of Viking 29, the thermophotovoltaic hybrid car. The remains of Viking V’s chassis and body are stored outside the VRI.

MORE ECONOMY COMPETITIONS

In July 1980 Western Washington University sponsored the Sea to Sea Econorally. Viking IV was one of eight entries from the United States and Canada. The Econorally was an actual road test from Bellingham, Washington, to Washington, D.C., a distance of 4000 miles. The cars were driven at normal highway speeds with no special driving techniques (such as coasting) allowed. An observer from a competing team (not from Western) always rode with the Viking driver, Larry Graf. The rally took eleven days and passed through Seattle, Portland, Boise, Salt Lake, Cheyenne, Denver, Kansas City, St. Louis, Philadelphia, and Washington, D.C. The rally included emissions testing at Chrysler emissions lab in Detroit. Viking IV was the winner with an average of 87.32 mpg. The total cost of diesel fuel from coast to coast was $46.75. In emissions Viking IV passed 1980 federal requirements at 0.001 grams/mile hydrocarbons, 0.752 grams/mile carbon monoxide, 1.062 grams/mile oxides of nitrogen. Viking IV also won the performance testing done before the rally left Bellingham.

In the second Sea to Sea Econorally, again a road test from Bellingham to Washington, D.C., and this time sponsored by UNICAL, Viking IV captured first place in all three Econorally categories for prototype vehicles seating two or three individuals. It averaged 87.5 mpg in fuel economy and had the best performance and emissions.

In 1985, the Viking IV's 1978 1500 Volkswagen Diesel engine was modified with a turbocharger and not only met the 1978 emission standards, but also surpassed the 1985 requirements by a wide margin. In the next UNICAL rally, the Three Flags Econorally from Vancouver, B.C. to Los Angeles, the VRI entered several Viking cars. In this rally, Viking IV again won first place and exceeded its earlier fuel economy record by averaging 88.2 mpg.

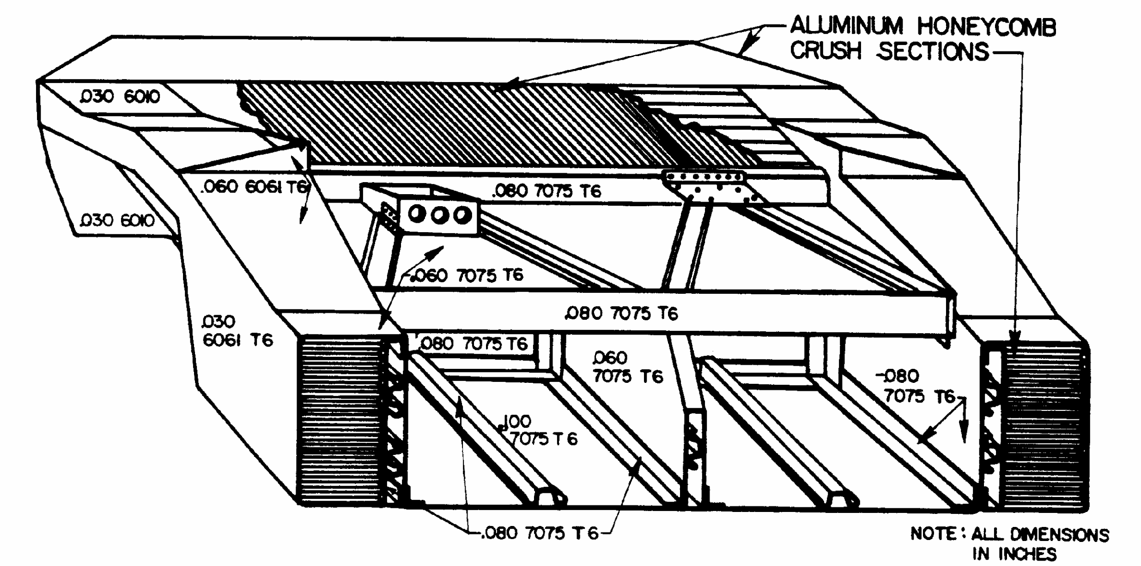
(For an account of the Three Flags Econorally, and a picture of several Viking cars entered in it, turn to the end of Chapter 4.)

CHAPTER 4

Safety First – Viking Car VI

Viking VI

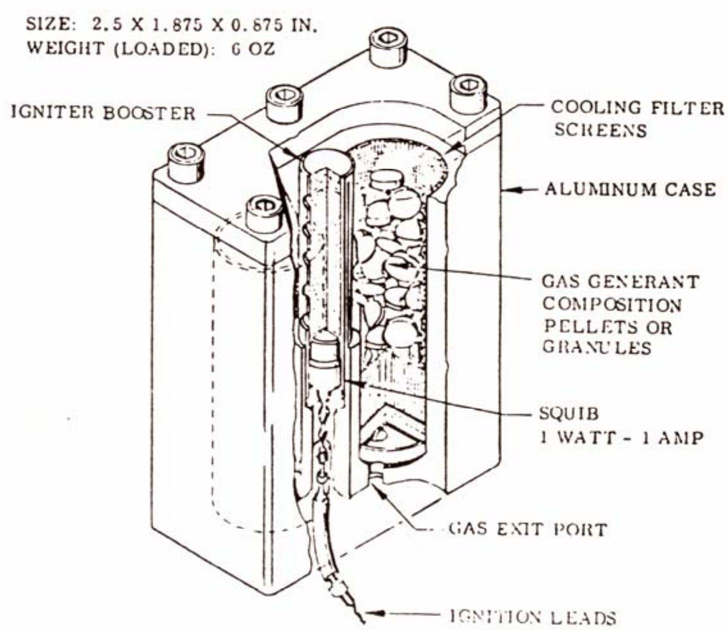
Viking VI was developed under a $200,000 contract with The National Highway and Traffic Safety Authority in 1978. It was designed to see if it would be possible to build an ultra light (1320 lbs.) fuel-efficient vehicle capable of providing safety at least as good as that provided by full-sized cars. In its performance in a crash test at Dynamic Science in Arizona on May 29, 1980, Viking VI demonstrated an ability to provide survivability for the occupants in a 41.2 mph crash. In order to provide good crashworthiness in such a light vehicle, many unusual design steps were taken. To make sure that the occupants would not be crushed in the crash event, the central monocoque chassis section was made extremely stiff with 1.5 mm to 2 mm 7075 T-6 aluminum sheet and hat section riveted together. This structure was obviously stiff enough as it only suffered a 4 mm permanent deformation after the crash event. The front and rear chassis sections were designed to crush at much lower loadings to provide a manageable crash pulse.



Front Chassis Pictorial

The front and rear chassis panels were made from 6061 T-3, .75 mm thick. The nose section of the structure ahead of the toe board was filled with aluminum honeycomb material. Mr. Sol Davis of Dynamic Science advised using aluminum honeycomb material with crush strength of 100 psi over an area of 400 square inches for a 40,000 lb. force through the available passive restraint air belts.

Although the original design of the car had called for a passive belt design, the only pyrotechnic inflator available mandated an active belt system for the crash test. Mr. M. Fitzpatrick of Fitzpatrick Engineering designed and static-tested an "in-belt gas generator," which Vehicle Research Institute personnel have installed in a functional passive restraint air belt system on the second iteration of the Viking VI design. Once the problem of the in-belt inflator was solved, it became possible to complete the passive restraint design originally intended. A simple peg-in-hole system, independent of the main hatch latching system, solved the problem, and the belt end was riveted up to the hatch with aluminum rivets that shear off at about 200 lbs. force. A notch was cut into the forward face of the peg so that relative motion during the crash sequence would shear the rivets before the 2200 lbs. force limiters started to stroke, ensuring that there would be no excessive "g" loading at the beginning of the stroke.

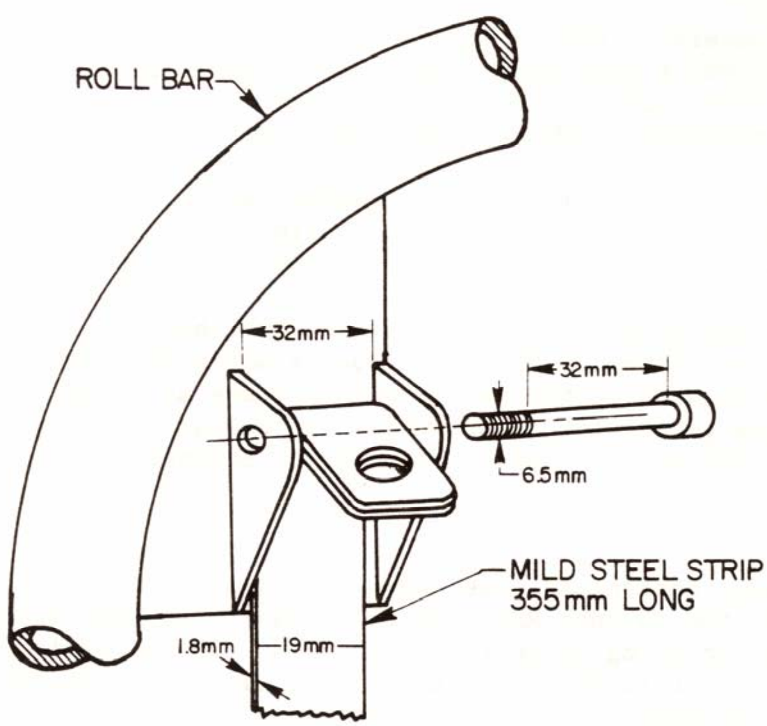


In-belt Gas Generator

The gas generator chosen for use as the inflation source for the air belt systems was a generator originally manufactured for installation in a steering wheel hub and used with a driver airbag system. The gas generator was supplied by Thiokol and loaded with 115 grams of DLZ 113 gas generate (50 gms of pellets 0.120 inch [3 mm] thick and 65 gms of pellets 0.060 inch [1.5 mm] thick). The igniter charge was 3 gms of UIZ-172 with 12 gms of $FeS0_4$ as a neutralizer. The cooling screen was 0.7 inch (18 mm) 21 strand Gold with a 2-12 mesh and 3-40 mesh filter screen.

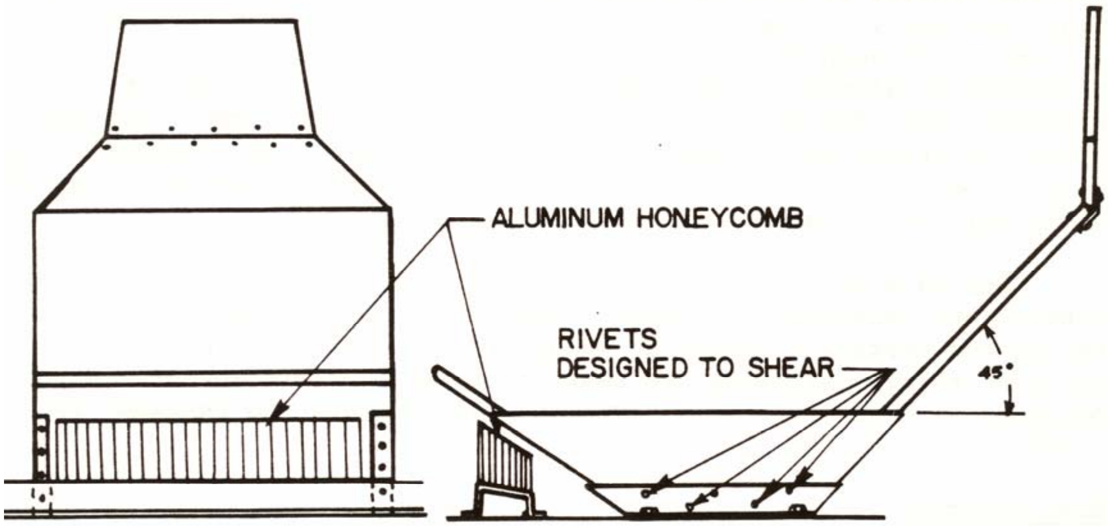
The gas generator was bolted to a gas distribution manifold with two three-quarter inch (19 mm) T.D. exhaust parts which distributed one-half of the total flow to each of the two air belt systems. This type of gas generation distribution system was based upon that used in the Calspan RSV as modified by Fitzpatrick Engineering.

The air belt design was based upon a design by Fitzpatrick Engineering and Calspan for the Calspan RSV. Certain changes to this basic design were necessary prior to using it in the Viking VI. To be consistent with desired anchor point locations in the Viking VI, the inflatable portion of the belt was shortened. Also, due to the fact that no force-limiting belt webbing was readily available, standard nylon webbing was used with the idea that a mechanical force limiter could be implemented later if desired. The retractor used with the air belt system was a VW Rabbit retractor. A Honda pivot loop became necessary in the final design iteration.



Force Limiter

To create as little air resistance as possible in the vehicle, the seat design features very little padding and a rather high rearward angle in which the occupants recline. In an effort to attenuate the “g” loads, a crushable, aluminum honeycomb block of 24 psi (1.7 Kg per cm^2) crush strength (part #38-5052-.007-1.0) and 45 sq. inches (290 cm^2) area was placed under the driver and passenger seats for the test. During sled testing it was noticed that the best overall trajectory control and under-seat honeycomb crush for the occupants was maintained if certain rivets that connected the seat body to the floor bracket were allowed to shear, thereby allowing the seats to rotate forward and stay with the occupants. This seat-shearing-rivet concept was retained for the crash test.



Seat Shearing Rivets

Since the air belt was a two-point design (torso belt only), some form of lower body restraint was necessary. Originally, a VW Rabbit knee bolster had been installed in the Viking VI. However, it was determined during sled testing that the bolster was simply too "hard" for integration into the Viking VI structure, so it was discarded in favor of a new knee restraint designed specifically for the Viking VI.

Since no crash history existed, the crash pulse of the Viking VI could only be estimated. In order to prepare for a crash test and also to satisfy the desire to maximize the stroke efficiency of the air belt system, Fitzpatrick Engineering designed a mechanical force limiter for use with air belt systems.

For the Viking VI crash test, an energy absorber system—composed of a tape width of 0.75 inches (19 mm), a tape thickness of 0.071 inches (1.8 mm), and a roller diameter of 0.250 inches (6 mm)—was used for both the driver and passenger systems. The tapes and rollers were lubricated with grease before the test.

With an air belt design, it is very important to locate the belt anchors so that the belt passes across the chest in a manner where proper head support will be maintained as the head rotates forward during the crash. Additionally, the anchors must be located so the belt force transmission angles are as efficient as possible. In order to achieve this efficiency, the original lower anchor had to be moved 3 inches (76 mm) rearward to the bulkhead immediately behind the seats; the original upper anchor had to be moved upward and inboard a total of 8.75 inches (222 mm) on the roll bar.

For the crash test, 50th percentile, Part 572 dummies were used in both the driver and passenger positions. A test "window" for velocity of 41+/- 1 mph was chosen. Any velocity outside this range would result in an aborted test. The vehicle front-end energy absorber selected for this test (psi Kg crush-strength aluminum honeycomb) was expected to exhibit a static crush of approximately 22.5 inches (572 mm).

The Viking VI crash test was conducted by Dynamic Science on May 29, 1980. The actual crash velocity was 41.2 mph with a rebound velocity estimated at 3 mph (5 Kph). Sensing time for air belt actuation was selected and verified at 11 msec.

Table 1

Injury Measures Received for the Driver and Passenger

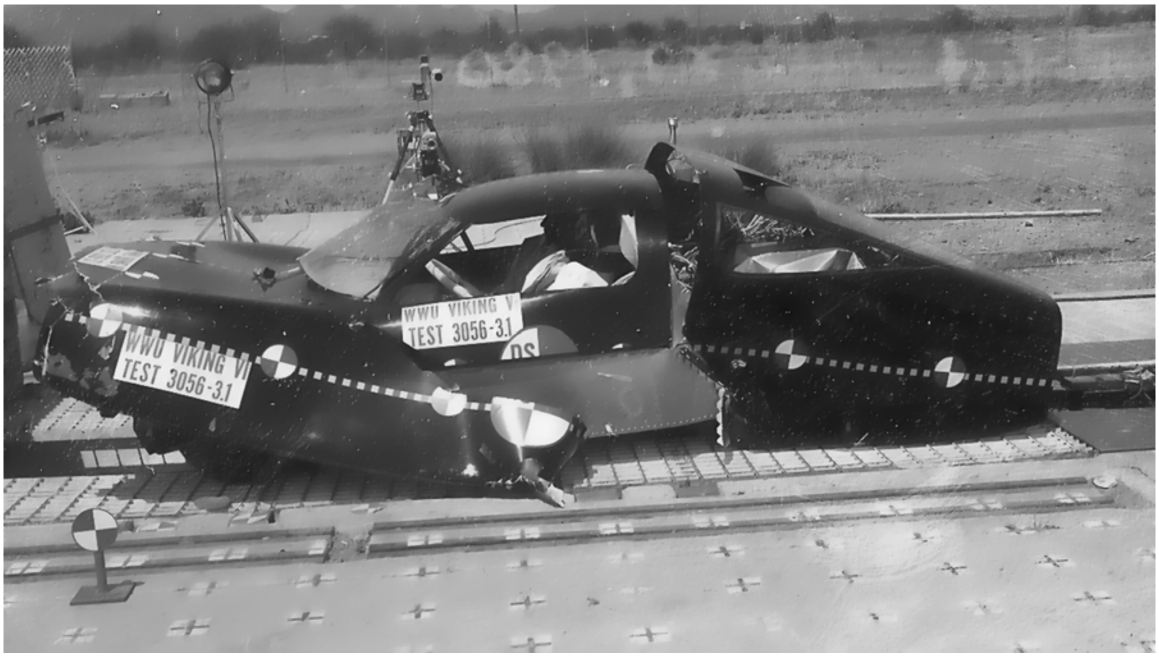
	Driver	Passenger	"208" Std
HIC	*552	286	1000
Pk. Res. Chest g's (-3 ms)	44	51	60
Pk. Vert. Chest g's (-3 ms)	24	24	NA
Pk. Femur Loads			
Left	1031	1080	2250
Right	1130	819	2250

***Roll bar hit dummy on side of head controlling HIC**

As is evident from Table 1, all the measured injury parameters are well below the FMVSS 208 injury criteria limits. We believe these results are especially pertinent since they show that it is possible to design a very small car and still protect the vehicle occupants within established injury guidelines, even at velocities greater than required by present standards. Admittedly, only one impact mode was tested here; however, we believe that, in a program where more development and testing were possible, these results could be extended to other accident modes as well.

The seats performed pretty much as expected in that the rivets previously discussed sheared according to plan. However, not quite as much honeycomb was crushed under the seat pans as desired because some other rivets—holding the plate to which the under-seat honeycomb had been bonded—sheared, allowing the honeycomb to slide partially out from under the seat pans. Perhaps if this unintended shearing had not occurred, the chest vertical ”g” component would have been a little less than the 24 “g’s” actually measured. There was very little knee restraint crush for either the driver or the passenger (0-1/2 inch) as the upward tilt to the seat pan not only effectively prevented the lower body from translating very far, but also absorbed, through bending and crushing the honeycomb, most of the lower body energy.

The crash pulse “g’s” were fairly high in the beginning of the crash. However, in spite of the fact that these “g’s” peaked at approximately 56 “g’s” and were quite high for a relatively long time resulting in a very short crash pulse duration of only 72 msec, the force limiter operation effectively limited body “g’s” to rather low values.



Viking VI, Version One Crash

.

The crush of the vehicle’s front end was different than anticipated in that rather than crushing accordion fashion for the complete stroke, one-half overrode the correctly crushed section and was incompletely crushed. The rest of the vehicle structure absorbed more energy than anticipated, which apparently helped offset the odd crush behavior of the aluminum honeycomb itself.

There was significant pitching of the vehicle late in the crash event; however, it was believed the center-of-gravity (C.G.) of the vehicle was artificially high due to instrumentation mounting locations being generally much higher than those in a normal vehicle C.G.

Static crush of the vehicle was estimated at 18-19 inches while dynamic crush measured from the films was approximately 25-26 inches. This substantial difference indicated that the vehicle may have had a fairly high rebound velocity. The actual rebound velocity was difficult to establish because of gross movements and rotations undergone by the vehicle accelerometers, which were mounted in areas that suffered severe bucking. Film analysis showed the vehicle rebound velocity to be approximately 3 mph for a total vehicle "delta V" of 44 mph. If a measure of safety is to be provided, then the side of the vehicle must be made stiff enough to force the striking car to provide nearly all of the ride-down distance through crush in its nose. The Viking VI used side boxes 6 inches by 13 inches in cross section made from 7075 T6 aluminum sheet 115 mm thick, reinforced at critical points with 2 mm thick

7075 T6 aluminum hat section. A transverse panel of 7075 T6 aluminum 1.5 mm thick behind the seats anchors the rear end of the box while the upper dash panel structure provides a front transverse stiffener as well as providing a reaction point for the knee bar. A transverse member under the front edge of the seats further stiffens the middle of the structure. Additional stiffening is provided by aluminum honeycomb bonded to the face skins with epoxy adhesive. The inner surface of the side tanks had a 500 mm thick layer of rigid polyurethane foam covered with 13 mm of ensolite foam. The entire cab is skinned with dark brown vinyl upholstery material.

The windshield is mounted well forward of the driver to give maximum ride-down space for the occupants' heads during a crash when they are riding forward in their belts, which are stroking the force limiters previously described. Other benefits of the forward mounted windshield are that the angle of vision subtended by the "A" pillars is very small, and the degree of sun-shielding makes separate sun visors unnecessary.

Extensive use of aluminum played an important part in weight reduction. Not only were all major castings for engine, transmission, steering, suspension, and brakes made from aluminum alloy, but also the chassis lower body monocoque tub was made from aluminum sheet. All of the parts cast in the VRI were cast from 356A-T6 aluminum alloy with strontium modification to improve grain structure. The parts were heat-treated to T6 or T61 to improve strength and machineability.

The center monocoque was made from 7075 T6 aluminum alloy 0.080 inches thick except for the critical toe board which serves as the reaction member for the aluminum honeycomb deformable section in the nose of the car. Localized longitudinal and transverse stiffening was provided by corner reinforcement angle sections and 0.060 inches of 7075 T6 alloy hat sections. The forward and rear bays were made from 0.050 inches of 6061 T4 aluminum sheet to form a structure strong enough and stiff enough to carry normal usage loads but able to deform at a survivable rate during a crash. The overall weight of the hull was kept to 225 lbs. Previous experience with Viking IV's aluminum aerodynamic skin and Viking V's glass reinforced polyester matrix body led us to believe that there is not a lot to choose between the two materials for one-off prototypes in terms of weight. The glass reinforced polyester skin is far easier to build. The body skins for both cars were initially very light (220 lbs.), and the panels used on the crash test car had very little filler. The second fuel economy, emission, and performance car suffered from a misunderstanding with campus janitor service members. They took it upon themselves to destroy some of the body plugs and mold before the final body parts were fabricated. As a consequence, the show car body which was on display in Japan weighed about 250 lbs.

Suspension components were specially fabricated to save unsprung mass for improved ride and road holding. The wishbones for the unequal length, non-parallel system were made from 0.040 inch thick 4130 chrome-moly steel tubing 0.750 inches in diameter. The suspension system made use of coil springs wrapped around the shock absorbers and forged steel spindles and uprights at the front, which mount forged aluminum 6061 T6 steering arms. Aluminum discs with copper-iron metal spray surfaces were cast and machined for front and rear. The front units have given no trouble, but the more heavily loaded rear units have actually melted the aluminum from the middle of the iron-aluminum-iron sandwich. As a consequence, the experimental discs were replaced with cast iron units. The front wheel diameter was kept as small as possible for several reasons. The elimination of bumps in the upper body allowed for the wheel travel of larger wheels which improves aerodynamics. Smaller intrusions into the car center at full lock made it possible to fit a good aluminum deformable structure. Smaller skirts could be put over the front wheels at full lock, which saves frontal area.

The styling of Viking VI was based on the premise that a smooth aerodynamic form could provide an attractive appearance. The rounded elastomeric urethane 5 mph bumper provides a curved surface unlikely to injure a pedestrian struck in a low speed impact. In fact, the 40 degree sloping windshield would be likely to deflect a person clear over the vehicle with a minimum second impact injury. The headlights were set well back from the front so that they would be out of the 5 mph bumper strike zone. Also, the front of the car was low enough that the most forward part of the body high enough to meet the federal headlight height regulations was almost at the leading edge of the windshield.

Early in the design program it was decided that a good aerodynamic form would be required to give the expected fuel economy. Initial wind tunnel tests of an one-eighth scale model indicated that a drag coefficient (Cd) of .26 was possible on the already low frontal area of 15.1 sq. feet. Coast-down tests and rolling drag measurements done at the California Engineering Center indicate that the actual Cd was closer to .21.

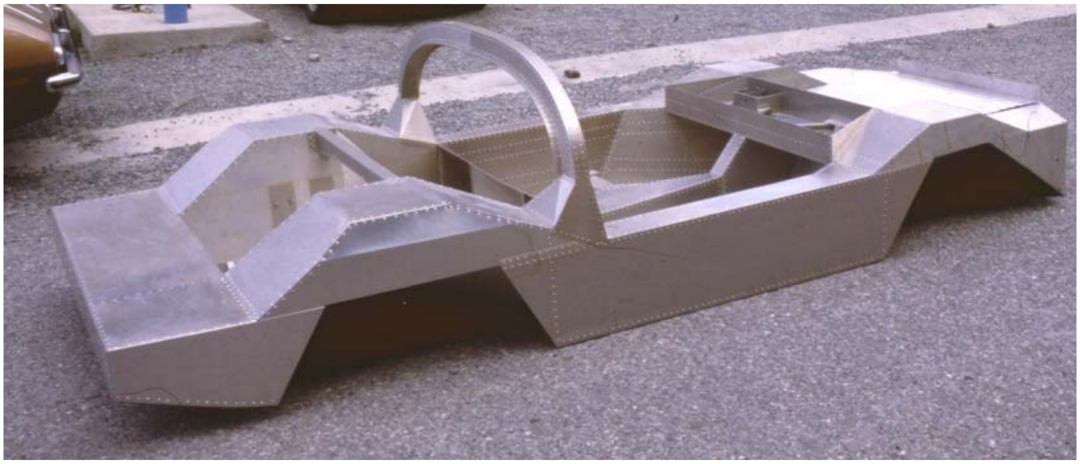
Removal of the headlight cover panel increases the Cd to .25 and increases wind noise from a very low level to more normal levels. Fuel economy could be expected to be noticeably poorer on a highway driving cycle. To cover the headlights a flat wrap panel of hard abrasive resistant polycarbonate was used. The panel has been remarkably free from scratches, but a demister/defroster system should be added. During a snowstorm in the mountain passes of Oregon, the headlight range was seriously compromised.

Viking Headlight Detail

Aerodynamic stability was a matter of some concern as the center of gravity of the vehicle is well to the back, and the lateral center of pressure of well streamlined vehicles tends to be far forward. As a result the nose section of the car is quite low and has well rounded contours. The rear sections are quite slab-sided, and the rear wheel skirts drop to within several inches of the ground. The net result of moving the center of lateral effort aft and fitting the rear end with tires of much larger footprint than those of the front gave very satisfactory crosswind performance. All turn signals and repeater lamps were fitted flush with the body to further reduce aerodynamic drag. The rear lamps are mounted just ahead of the rear clear polycarbonate cover to maximize rearward vision in parking maneuvers. In fact, when backing up, the driver can actually see the rear bumper.

Since it was considered desirable to provide easy access to all mechanical, electrical, and plumbing components of the vehicle, the rear body panel tilts back on hinges at the extreme rear of the body, providing good access to the engine. Simply removing the easily accessible hinge pins allows the entire rear aerodynamic skin to come off the car. As there are no electrical connections to this panel, removal is simple. A number of easily accessible cap screws that hold down the transaxle cover can be removed, and the entire power train is exposed and can be worked on from above rather than below. The battery is readily serviced in the extreme right rear section of the chassis.

When the hatch is lifted and the instrument backing panel lifted off (no fasteners), all of the instruments and associated wiring are exposed for easy servicing. In addition the three clutch and brake master cylinders are exposed. When the cover to the tunnel between the seats is uncovered, the switches and attendant wiring are exposed. The seatbelt retractors and shift linkage also lurk in this tunnel. Only removal of the front wheels presents a problem. The car must be jacked up so the wheel nuts are exposed, and the wheel will only come out of its well when pointed straight ahead.



Viking Aluminum Chassis

Finding seats that would fit into this low built car and could be adjusted to fit a 95th percentile male and a 5th percentile female without incurring a weight penalty proved to be a problem. Finally, it became necessary to design and construct special seats. The seat chassis were made from 2024 T6 aluminum skinned balsa core material riveted together with doublers at high stress areas. The seats were then upholstered in conventional materials. The adjustment mechanism is unique. It was determined that the best driving position for a tall person was a steep reclining position while best vision and comfort for a short driver was achieved by providing a more upright driving position with the seat closer to the dashboard. The 105 degree angle between the seat back and seat bottom is maintained at all times. Standard seat rails were mounted outboard of the seats to give the lowest possible seating position while the seat angle adjustment was provided by means of an adjustable aluminum wedge controlled by a simple knob on the floor.

Viking VI Seats

The first engine used in Viking VI was a 1600 cc Subaru. It was chosen because of its light weight (185 lbs.), boxer layout, and proven ability to meet exhaust emission standards. Unfortunately, the engine has somewhat too much displacement for best fuel economy. Eaton valve disablers were used on the intake and exhaust valves on the front cylinders of each bank so that the driver could switch off two cylinders in situations not needing high power output. Although the front two cylinders are motoring, there is very little power loss because pumping losses are almost eliminated as the valves are closed. The energy required to compress the air in the cylinder is almost entirely recovered on the expansion stroke.

The remaining two cylinders are able to function at much higher Brake Mean Effective Pressure (BMEP), which provides improved thermal efficiency. Because of low vehicle drag, a low numerical final drive ratio can be used with large diameter wheels and tires. At a given vehicle speed in top gear, the engine will operate at reduced rpm and increased throttle opening, which reduces pumping losses.

One of the prime objectives of this integrated research safety vehicle was to improve vehicle fuel efficiency without compromising safety goals. Improvements in engine efficiency, aerodynamic drag, and weight reduction all played a part in the demonstrated high mileage of the vehicle. On an E.P.A. test, Viking VI achieved 40.4 mpg in the city and 66.6 mpg on the highway. Gravimetric data showed that even better results could be obtained with further engine optimization.

Although acceleration, braking, and handling were not the highest priorities for the Viking VI program, VRI personnel have a long standing personal interest in these aspects of vehicle design. The basic suspension system utilizes coil-over shock absorber units located by a long and short arm, non-parallel wishbone system at each end. The roll center at the front is 50 mm above ground level while the rear roll center is 100 mm above ground level. The virtual swing arm length both front and rear is 190 mm. Camber gain at 3 degree roll maintains the outer wheel perpendicular to the road surface. The tire footprint at each end of the vehicle is high for the load carried and in direct proportion to it.

Nine inch disc brakes are used at each wheel with aluminum brake calipers. Two master cylinders are used with a balance beam mounted integral with the pedal so that a simple screw adjustment can adjust the percentage braking that each end of the vehicle receives. At this writing the unit is not servo controlled by weight in the trunk.

Acceleration and coast down tests have been run on the car. It has achieved a 8.95 second time from 0-60 mph (0-96 kph) and a time of 16.8 seconds for the standing start 1/4 mile. The car has been driven from Bellingham, Washington, to Santa Ana, California, and back up the coast of California, Oregon, and Washington.

Viking VI was tested for exhaust emissions at the Subaru Technical Center in Santa Ana. After some preliminary work to dial in the best compromise for fuel economy and exhaust emissions, Viking VI met the 1982 exhaust emission requirements without a feedback loop carburetor or fuel injection. This accomplishment provides a graphic example of what a reduction in weight and aerodynamic drag can do to reduce emissions and improve fuel economy while limiting hardware costs.

A most significant conclusion based on the results of this program is that occupants in a very small, lightweight vehicle can be protected in a crash. The work done with the in-belt inflator shows that effective passive restraint air belt systems are viable and show promise of combining the best features of air bags and belts, albeit at a high cost.

NHITSA paid to transport the Viking VI to Kyoto, Japan, for a Safety Conference where it was on display. While it was in Japan, Subaru tested it in their wind tunnel and found that the correlation between coast down tests done on the Skagit flats and those done in Subaru’s wind tunnel were excellent.

Michael Seal with Viking VI on Display in Kyoto, Japan

Three Flags Econorally,

Front row – Viking VI, Viking IV and Missouri's Bearcat,

Rear row – Unknown, Viking V, Avion, Viking VII

I remember . . .

Growing Up in the VRI—
The Three Flags Econorally

by Lisa Seal Christensen

We moved to Bellingham when I was a child. Early students to the VRI program will remember me as the middle daughter (often in pigtails). My sisters and I spent a great deal of time up at Western. I didn't realize until later what a unique opportunity I was given to grow up the way I did. The various car rallies became our summer vacations.

I remember the construction of all the Viking cars, some more clearly than others. Although I was never officially a VRI student, I did spend a great deal of time in the labs (especially when I was a student at WWU). Dinner time conversations often revolved around what was happening in the program. Bill Brown, one of the technicians in the program, often took pity on my car woes, and would help me repair various parts on my "Le Car." (An off-hand remark he once made later became a reality: he advised me to find myself a husband who would do the car repairs for me.)

In 1986 a former VRI student found sponsorship and organized the UNICAL Three Flags Econorally. The Rally was to start at the Expo fairgrounds in Vancouver, BC, and end at the Mexico border. The sponsor was looking for as many entries as possible for this contest, so the VRI entered everything it had: Viking IV, Viking V, Viking VI, Viking VII, and Quattro San (Subaru's prototype AWD car donated to the VRI). Originally, Quattro San was not going to be entered in the contest; it was just going along as a chase vehicle. But we were told that if it were entered, the fuel costs would be picked up by the sponsoring company (UNICAL). This project was an ambitious one for the VRI. With so many experimental vehicles making the trip, we were short on team members to get everything done. I volunteered to run for parts, sand bondo, make fast food runs, and do anything else I could think of to support the effort. My mother and I also agreed to form a team to enter Quattro San into the competition; this experience was both exciting and daunting for me and was filled with many "Firsts."

One of the first events in the competition was the "auto cross," which involved driving the car at a high rate of speed around cones in a parking lot. My dad put his motorcycle helmet on my head, gave me a few quick tips, and sent me on my way. It was great fun! I later entered my Le Car in several local auto cross events.

There was a ceremonial start to the race at the Expo fairgrounds, but Viking's V & VII had mechanical difficulties, and started the race a day behind the rest. Many of these events came down to all night work sessions, and heading out on 1000+ mile trips with little or no testing on the vehicle. But there was always a great sense of camaraderie in these late night work sessions. On this occasion, Mom and I had stayed behind to act as a chase vehicle for the two cars (in case they had further problems on the road south). We caught up with the rest of the fleet late the next day in Salem, Oregon. (This trip was the first time I had driven a car out of the state.) When Viking VII continued to have problems on the road, I was entrusted with the credit card and told to make sure the "boys" got checked into the hotel OK.

Other memorable "firsts" for me occurred, such as navigating from downtown L.A. to the Queen Mary in rush hour traffic. I also took a turn towing Viking V home (behind Quattro San). Going down the Grapevine, it became apparent that Viking V wanted to take the lead. The car was being pulled on its own wheels (out of gear) with a rigid tow-bar; lights were hooked up, but not brakes. Viking V would attempt to push Quattro San, causing it to fishtail. Accelerating would straighten it out, but unfortunately there was a military convoy traveling ahead of us, preventing me from accelerating to a speed to avoid the fishtailing. At the rest area at the bottom of the hill, I was more than willing to give up the driving duties to my dad.

I remember . . .

Family Vacations,
Turning Left in Mexico and Finding Cows in the Dip

by Suzanne Lautenbach

What I remember most about growing up with my dad are the vacations that were centered on a car rally. The Three Flags Econorally ended in California at the Mexican border. The Wilcox Company loaned the family its experimental car to allow us to extend our vacation into Mexico. So we ended up driving off from the rally with a car that would only turn left. It was a diesel conversion car that got 40 mpg when diesel was only 14 cents per gallon in Mexico and gasoline was over 70 cents per gallon. This car was bright yellow and stuck out like a sore thumb wherever we went. In Mexico City, we were driving in one of those large circles around a statue, and my dad was simply following traffic, trying to turn left and exit when a cop noticed us and pulled us over—claiming some sort of traffic violation. The cop told dad that he could pay the fine to him right then and there. Well, dad did so, but asked about it later when he was lecturing at the University of Mexico. He found out he had been conned by the cop. We happened to be out again in our bright yellow car when the same cop pulled us over and offered to take dad's money again. This time dad asked for his badge number, and the cop started to back away so dad couldn't see the badge, and finally he ran away.

We did a lot of driving while going through Mexico. One particular road had many dips in it, but as you looked ahead, you couldn't see the dips or what was in them. So, of course, dad didn't see all the cows in the road until the car came to a very sudden stop. All the stuff on the back ledge fell on Lisa, Cathie, and me as the car crashed into the side of a cow and came to a halt. There was manure all over the windshield, and the car wasn't going anywhere as the fan had gone into the radiator. We were taken in by a friendly Mexican whose family had a motel and restaurant, and given something to drink, powered milk, I think. Dad thought we would be in trouble for hitting a cow, but it was the farmer who could get into trouble because he wasn't supposed to have the cows in the road. This accident made me late returning to school that fall, but, boy, did I have a great story to tell for an excuse!

CHAPTER 5

Professor Seal – Researcher and Teacher

Viking VII and Viking VIII

Viking VII was Michael Seal's personal project. In 1981 and 1982, he received two awards from Alcoa of $7,500 each to further his personal research. He decided to build a high performance sports car to determine if high fuel economy and clean exhaust could be maintained while offering "Supercar" levels of performance.

Michael Seal Working on the Plug for Viking VII

For Viking VII, a 10th scale model was made and tested in the wind tunnel. Then, a wooden plug was constructed and a mold was made. The first body was Kevlar but, since it was not post cured before being painted, it cured from the heat of the sun and left a pattern that showed through the paint.

Michael Seal with the Kevlar Body on Viking VII

Viking VII was later remade with a slightly longer tail in fiberglass. The chassis was an aluminum monocoque.

The first engine used in the vehicle was a highly modified 130 hp Subaru engine with a four-cam, four-valve head, developed under a contract from Subaru.

Although fuel economy on the highway is only 50 mph and less on the LA four-cycle, the car accelerates to 60 mph in 5.3 seconds and can generate over 1 “g” in cornering power.

Viking VII with Longer Body on Display at the World Fair in Vancouver

The car won the A-Modified class in local Autocross competition two years running. In 2002, Dr. Seal decided to change the engine to a 1990 Ford SHO. This conversion has taken considerable modification to the engine compartment because it is a very tight fit.

Viking VII's First Subaru Engine with Cast Heads

Viking VIII was an effort to capitalize on the success of Viking VII and introduce a limited production sports car to be built in Costa Rica and sold in the USA. Although the car would look like the successful Viking VII, it would incorporate an American built engine transaxle assembly from Chrysler and use an all composite monocoque body chassis unit. A single prototype was built, along with tooling suitable for an initial production run. Unfortunately, the client ran into financial difficulties, and the initial production run never materialized.

I remember . . .

A Teaching Standard to Live Up To

by Tom Hull

I was a student at the VRI from 1981 to 1984. From that time, I have two lasting memories about Dr. Seal.

#1—Like a normal dummy student, I split an engine off the drill press one day because it was not clamped down, as per all instructions. The mistake ruined the valve guide in my block. Upon hearing me confess my errors, Dr. Seal said he would help me fix it. This incident was, perhaps, the first time in my life that I had screwed up and someone had calmly offered to help me. With Dr. Seal's help, I machined a new valve guide and pressed it in the block.

#2—I did not understand secondary harmonics in four-cylinder engines after Dr. Seal's lecture. So Dr. Seal took me over to an old-fashioned drafting table and

drew up a large-scale diagram, explaining the concept in a different way than he had in class. I finally got it, and said so. He said, "Yes, I think you do. A lot of people just say they get it after trying a while, and they don't want to go on."

I have been teaching mechanics and machine shop for twenty years and still use Dr. Seal as the teaching standard that I try to live up to.

I remember . . .

One in a Million

by Cole Dalton

Wow, 35 years! Michael Seal is one of a very few number of people who continues to have a very profound and positive influence in my life. I have encountered only a few people who have such an incredibly inspiring effect on those that come into contact with them. This effect is not only the mark of a truly brilliant individual, but also a very gifted teacher. Over the years, I have stopped in from time to time and "caught up" with Dr. Seal on the current happenings at the VRI. Students and projects come and go through his program, but what always impresses me is the way he consistently inspires excellence with his quiet enthusiasm and dedication. When I left home and went off to college, I, like many, really had no idea what I wanted to do. My dad (another wise and influential person) told me that it didn't matter what I studied; what mattered was "to just find someone interesting to be around, and try to learn from him." Well, I found one in a million in Michael Seal.

(See description of Cole's 1979 trip to Detroit with Viking IV in Chapter 3.)

I remember . . .

The House of Dr. Seal

by Tim Roddick

Easily the most enriching time of my life was spent at the VRI, that is to say, the House of Dr. Seal.

After having become rather too accustomed to being a half-step out of sync with my surroundings, it is hard to explain the degree of excitement and the feelings of opportunity that came with being surrounded by people of similar interests, passions, and intensity. In fact, there were even folks "in deeper" than I! Many of our friends, families, & significant others, while displaying delight (& virtually infinite understanding), were more than a little curious and quizzical around this collection of wild-eyed, recently-enabled eccentrics. For us, though, it was a tonic (in fact, a veritable self-help group!) for vehicular enthusiasts (a.k.a. car nuts!) that many of us had been searching for most of our lives. It was all made (and let's be honest, only made) possible by Dr. Michael Seal.

Once when I was displaying just a little too much enthusiasm (read: inexperience) with my machining skills, I cracked a casting on the lathe tailstock by tightening down the stop too much. If there is a purgatory for machine tools it is to end up at the mercy of the students at the VRI—every student will understand completely what I mean by that! After I detailed my ineptitude to Dr. Seal, he gave the trademark "Well, it's better that you told me about it than having wandered off and left it, but you're still not off the hook" furrowed-brow look, and then he sighed rather heavily. "If only Bill Brown were here, the lathe would be back in operation in an hour's time …." After many years helping Dr. Seal to build up the VRI, Bill had recently passed away. Dr. Seal's reaction that day was one of the very "human" moments I remember that came despite our being completely surrounded (immersed, even) in technology on a daily basis. His long-time friendship with Bill exemplified the atmosphere that he instilled at the VRI. Creativity, excitement, curiosity, devotion, and commitment are but a few of the traits that Dr. Seal encouraged so successfully.

I remember . . .

Some of the Best Education I Have Ever Had

by Wes Williams

All I can say is that, for those who are privileged enough to go to college, it is almost always a life defining period. During much of my time at college, Professor Seal and his wife, Eileen, were very prominent people in my experience, not only in an academic role but also as role models for many of the other important aspects of life. Seeing first hand how a couple can work together, play together, basically go through life together with mutual respect for one another, and in basic harmony—that was probably some of the best education I have ever had. And I didn't have to pay tuition for it.

Composite Chassis for Viking VIII

Viking VIII

I remember . . .

A Memoir of Mike Seal — Teaching in China

by Claude Hill

One of the most unique and memorable experiences of Mike's career was "The China Trip." In the spring of 1986, Mike, Bill Brown, and Claude Hill were invited by the People's Republic of China to give a series of lectures at Chongqing University. Mike was to share his knowledge of automotive design, Bill was to provide the diesel expertise, and Claude was to present new developments in plastics technology. It was also an honor that Eileen Seal and Faye Hill were invited to accompany their husbands on this trip.

We all met in Hong Kong and flew to Beijing aboard a new China Airline 767. Only much later did we realize that this was the first of many unique contrasts that we encountered throughout the trip. Upon arriving in Beijing with a great sense of anticipation, we soon realized that no one was there to meet us, and we had limited means of communicating. Culture shock indeed in a very foreign land! After two anxious hours and several futile attempts to make telephone contact, our guide, Lin finally came to our rescue. Lin was a young Chinese university student, enthusiastic and proficient in his interpretative skills and a very friendly and gracious host throughout our three week stay.

The van ride from the airport was both unforgettable and representative of enormous contrasts in culture, infrastructure, and technology that were emerging in China at that time. The highway was new, multi-laned, and modern by any standard, but shared in some concordant way by cars, trucks, and about every type of wheeled vehicle imaginable: bicycles with unbelievable loads of produce, lumber, or household goods; person-drawn carts piled high with baskets of chickens, a washing machine, or TV set; ox carts burdened with coal, sand, or bricks, and pigs, cows, and other livestock destined for market.

A Chinese Trilogee

During our time in Beijing we were treated like royalty and escorted to the major sights. Tours of the Imperial Palace, the Ming Tombs, Tian'anmen Square, and a walk on the Great Wall gave a lasting impression of the antiquity and richness of the Chinese culture. One could sense that Lin was truly proud of his heritage.

From Beijing, our next destination was Xian, but first, we had another airport adventure! We arrived in adequate time for our 14:45 departure, but the electronic reader board indicated a rescheduled time of 16:00, with a notation "mechanical problems." This was a bit disconcerting since the flight was to be on an old Russian turboprop plane of unknown vintage. After much confusion and translation, Lin finally reassured us, "No worry, mechanical problem with reader board, not with airplane." Nevertheless, after more hours of waiting and another rescheduled time of 24:15, we concluded there really was no such time, and it must mean the flight will depart the next day. Seeking lodging, we took a wild taxi ride through the night which included only intermittent use of headlights ("it saves energy"?) with people, bicycles, carts and animals still on the road. The following morning we learned there was time for a quick side trip to the Beijing zoo to see the world famous Panda Bears—truly adorable creatures. Then back again to the airport, where after more waiting, delays, cajoling, translating and rescheduling, we were off in the Russian "bucket of bolts" to Xian.

The highlight in Xian was a visit to the excavation of the enormous tomb of terra-cotta warriors and horses—over 6000 figures in this life-sized army, most of which is still intact. The figures are over 2000 years old and were placed in battle formation in the Tomb of the Emperor. This is a remarkable exhibit in an area of China that is a treasure house of cultural artifacts.

Finally, it was time to get to work at Chongqing University. The first evening of our arrival, we were honored with a formal banquet, hosted by the President of the University. With abundant food, several rounds of toasts, and formal speeches, it was apparent that they were very appreciative of our contribution to their university.

It is difficult to say though how effective our teaching efforts really were. The students were very attentive and treated us with great respect. The most serious challenge, however, was the time-consuming translation and the interpretation of many technical concepts. We also came prepared with visual materials but the AV equipment was often barely functional and, much to our surprise, it was not uncommon for all the electricity to go off if someone else on the power grid had priority. But we put forth our best efforts, and the students seemed enlightened with our presentations.

Meal times in the dining hall offered some of the most intriguing and amusing moments. Because the produce that is grown is fertilized from the "honey bucket" and with no clean water source available, the safe option was to prepare the meal in a wok with boiling cooking oil. This usually resulted in a dish of oil drenched greens over soggy rice or noodles, mixed with some type of meat, which was sometimes identifiable. One evening we recognized a chicken dish—a really complete chicken dish—with all the bones thoroughly diced, the innards intertwined, and—after some chop stick exploration—what should appear but the claw feet. After a hearty laugh and some speculation on where those feet might have wandered, needless to say, *our appetite for this fare began to wane. We politely asked if there were any other food choices and were told that some previous visitors enjoyed their Chinese beer and sugar cookies. So it was for several subsequent meals. One day we found some fresh oranges and bananas at a street market. As a welcome change, we asked if we could have some fresh fruit with our meals. The next day a large bowl of plastic fruit appeared on our table. Something got lost in that translation!*

Of lasting impression were the unusual sights and the striking contrasts observed throughout the trip. For example, a factory with the latest state of the art microprocessor controlled production equipment was operating next to 19th century equipment on dirt floors with arduous working conditions for the employees. The street scenes were equally fascinating: the food vendors, curb-side piles of meat, live chickens and ducks ready for purchase, the open air street corner dentist, and the ever present bicycles and humans transporting enormous loads of goods. Perhaps most amazing of all was the amount of strenuous human effort being exerted in building projects, in rock quarrying, and road construction.

China's Open Air Market

The culminating experience was the departure from Chongqing. Lin left us at the airport with instructions regarding our flight arrangements and a telephone number to call if we had problems. After several hours of waiting and with no plane in sight, we thought it wise to call for help, especially given our previous experience with Chinese air travel. By now it should have come as no surprise that the phone system didn't work! With patience wearing thin and some sense of desperation setting in, we searched for help and found an English-speaking Chinese man who happened to be a professor at the university. He assured us that the plane would indeed be coming, and sure enough—after we had waited thirty two hours—it arrived. And bedlam erupted in the terminal. The professor advised us not to enter the fray. Instead he asked for our tickets and passports (gasp) and fought his way to, or perhaps over, the counter to get our boarding passes. Returning quite disheveled with documents in hand, he shepherded us to the departure gate, and we were on our way home.

As we left China, we reflected on the fact that if the country could ever get its infrastructure organized and mobilize its enormous population into a productive work force, China would be a formidable world economic power. Eighteen years later, are we seeing this trend emerging?

Front Row, Left to Right—Faye Hill, Clyde Hill, Bill Brown, Mike Seal, and Eileen Seal

Chapter 6

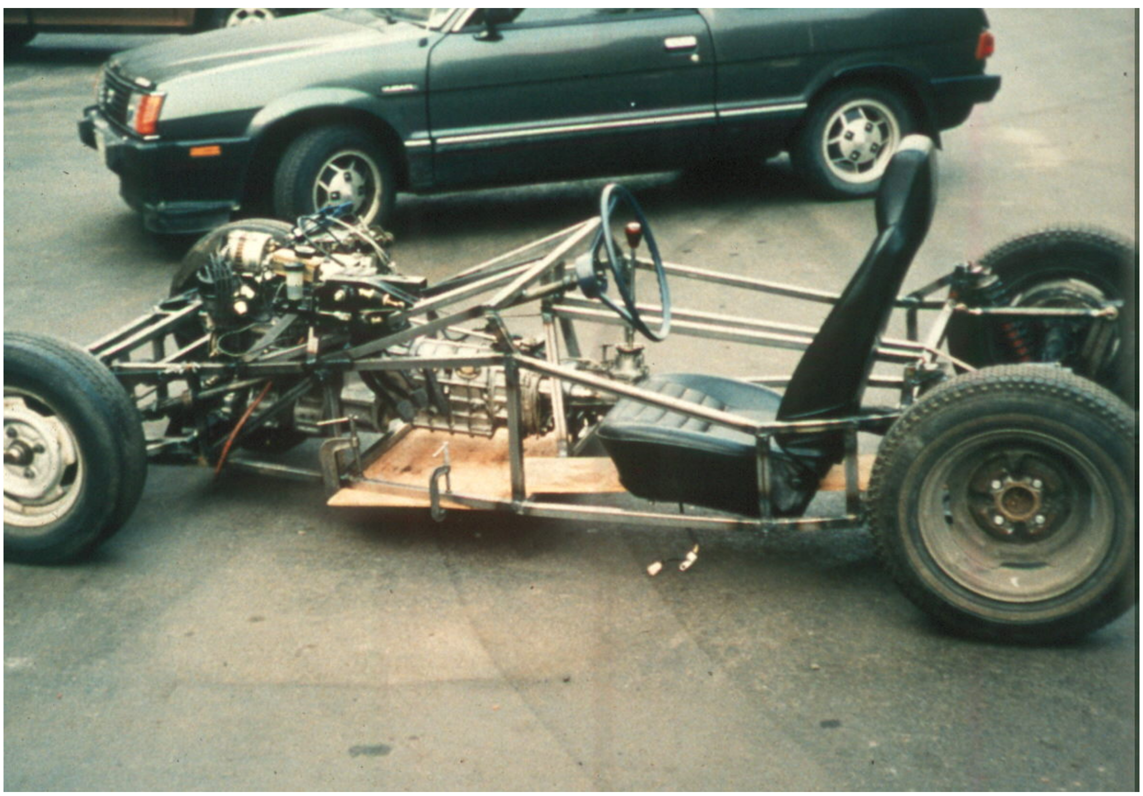
The Production Line – Autocrossers

Vikings 9-19

Viking 9 was a prototype for an Autocross type competition. It was designed to be a vehicle that students could build for themselves at low cost. Each student in the summer session of 1989 paid a $1,600 lab fee and purchased a 1970 vintage rotary engine (RX3, RX4, or RX7) car to serve as a donor car for the engine transmission rear axle for his own Viking car. Viking numbers 10-19 were assigned to the Autocrossers built that summer. Although these cars are socially irresponsible, a lot was learned about efficient limited production as the cars were built in nine weeks. The three courses were offered only the one summer. Although nine vehicles were started at the beginning of the summer, only about half the vehicles were running by the end of the nine weeks. However, after the summer term ended, the non-running vehicles were completed by their proud owners.

Autocross Chassis Construction

Autocross Bodies



Autocross Ready to Test

Completed Autocrosser

Chapter 7

The Solar Car – Viking XX

I remember . . .

Making the Impossible Probable

by Randy Weaver

I came to Western after spending a year lost in the large classes at the University of Washington. I wanted the smaller more hands-on approach. My friend Kerry Byford was taking a power mechanics class from Dr. Seal. Kerry knew of my interest in cars, so he encouraged me to take classes from Dr. Seal, too. The problem was I was trying to focus on my Manufacturing Engineering Technology degree from Western. This focus left no room in my schedule. Life went on for a few years.

In the fall of 1990 Kerry and I were taking a Numeric Control Machining class. As it turned out, only a small handful of us could make the old Bridgeport run. Dr. Seal asked for some parts for this solar car thing he was building, so Kerry and I machined the first motor mount. Dr. Seal ran off with the first part and then ran off to get some more sketches of parts to build. Pretty soon I was building wheels, motor mounts, steering arms, etc., for the Viking XX. Having never taken the time to take a class from Dr. Seal, I started putting in unreal hours in his shop in the VRI. I even spent graduation day machining some wheel parts.

In a few short months I had put in hundreds of shop hours and had come to realize that I had learned a great deal from Dr. Seal. He taught me and many others these important things.

- *Planning (meeting schedules)*
- *Goal setting*
- *Determination*
- *Hard Work*
- *Enthusiasm*
- *Continuous learning*
- *Leadership*
- *Vision*

His leadership and vision stick in my mind. He knows how to make the impossible probable, with the addition of a vision, a little hard work, and a lot of perseverance.

I have many memories about my travels with Viking XX, from Florida to Michigan, across Australia, and even across California. I spent many hours chasing a solar car, sitting next to Dr. Seal, sketching and discussing ideas for the next big projects which turned into Vikings 21, 22, and 23. After I graduated, I paid my tuition and wrote some papers on my experience with Viking XX and the VRI just so I could say I took some classes with Dr. Seal.

He has had a major impact on many lives, including my own. Without his leadership the VRI would surely not exist. Many of his students would not have had the chance to travel to the Salt Flats, Pikes Peak, Europe, and even Australia. His former students have made a major impact throughout the world, some working with Ford, GM, Chrysler, Mercury Marine, and even Boeing.

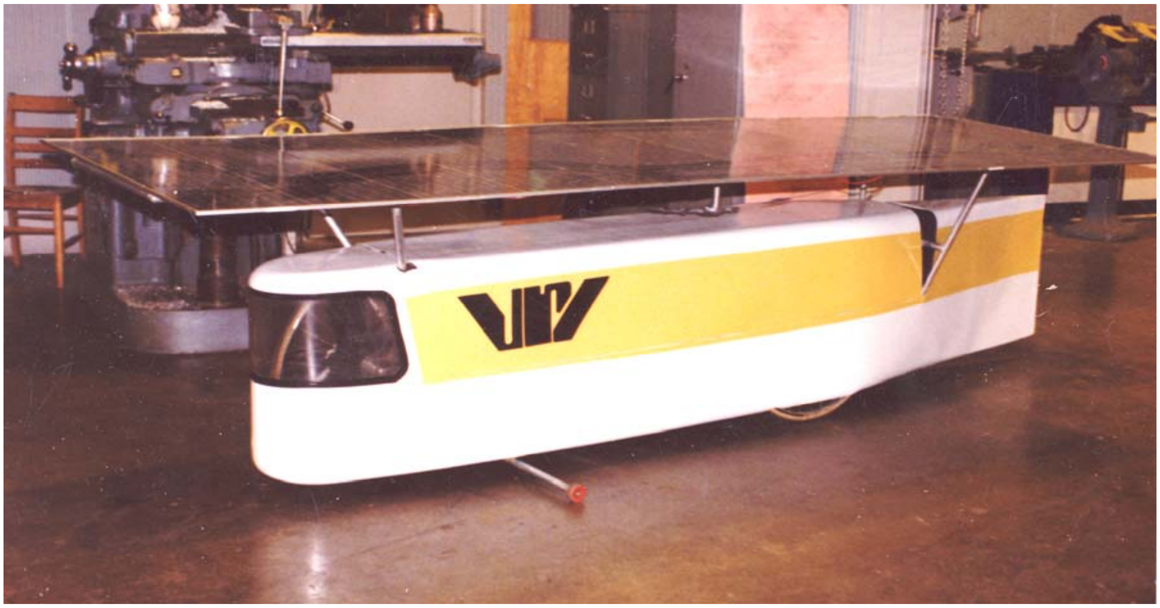
I am sure Dr. Seal may slow down on teaching formal classes and may spend a few less hours in the classroom, but he will never give up on teaching students about how to succeed with projects and life!

Thanks.

Viking XX

Viking XX came about because Eileen and Michael Seal were watching the Sunrayce across Australia on TV. General Motors (GM) won the race with its Sunraycer. GM then announced that it would not compete in the next race, to be held in three years, but instead would sponsor three university-designed vehicles. This announcement sounded like an interesting way to get to Australia. All that had to be done was submit a proposal for a vehicle, get accepted, build a vehicle that was nothing like anything that had been done at the VRI before, and win one of the three sponsored spots by competing in the race from Florida to Detroit in the summer of 1990. Thus began what Dr. Seal feels was one of the more technically difficult tasks that the VRI had attempted to date. In the fall of 1988, a meeting was called of all interested students. After a number of brainstorming sessions under Dr. Seal's direction, a very radical design was developed. It was nothing like the design of any of the solar cars that had entered the previous race. The design was submitted to GM and was one of the 32 accepted. Over half a million dollars and gifts-in-kind were raised, and a team of over 50 people worked on various parts of the design and construction. A team of 32 went to the GM Sunrayce, and, after Viking XX won a spot, a team of 18 later went to the World Solar Challenge in Australia.

The first project was to test the concept of power in a vehicle with solar panels. So a streamlined vehicle that had competed in high mileage competitions was converted to run on solar cells.



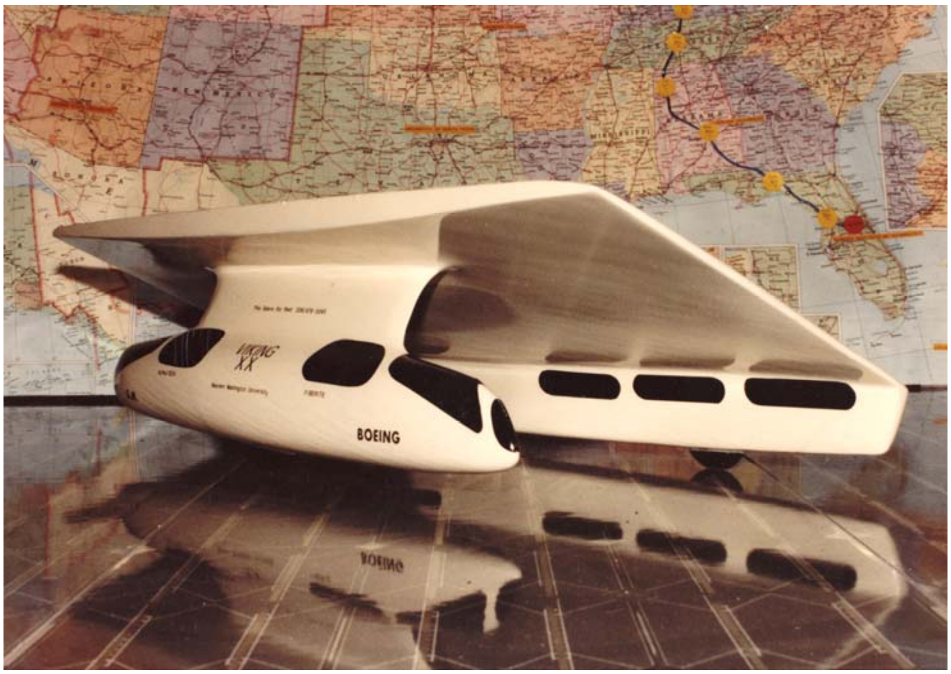
The VRI's First Solar Car

Students and faculty had discovered during the history of university competitions that a reliable machine would be of the utmost importance. Students at the VRI also knew that to win the GM Sunrayce or the World Solar Challenge they would have to build a vehicle that would optimize the number of solar cells that could be carried on the car and would, therefore, provide the car with the most powerful solar array. They decided to build a two-person car which, according to the rules, could carry solar cells not just on four meters of its length, but rather on all its body surfaces. The additional solar cells would supply a 50% gain in power.

An additional issue with the design centered on cross wind stability and increase in drag during cross winds. Initially, the car was designed with four wheels, and a driver pod in which the two occupants would sit back to back. Late in the design process, the organizers of the GM contest decided to add a requirement that the driver be able see upwards at 10°. Therefore, occupants had to be moved towards the ends of the driver pod, past where the wheels were to go. The only remaining place for wheels was between the two occupants. This change allowed a 26" wheel which gave slightly less rolling drag and slightly better load carrying ability but made the car less stable than it would have been with four wheels. A steering system was devised in which the two wheels on the battery pod side were used to counter steer, and the remaining wheel between the occupants became the drive wheel. Two wind tunnel models were built: one of the GM Sunracyer and one of WWU's design. The WWU design had less frontal area, and construction was begun on its various components.

This solar car is unique because it is designed to be turned around and driven from the other direction at midday so that the sloping solar panel can take maximum advantage of the sun's changing position. The 10,324 solar cells are space grade, monocrystalline silicon of approximately 15% efficiency. The peak power is 1800 watts.

The body is made from carbon fiber and other composite materials to form a monocoque chassis. The vehicle has a 10-horsepower Unique Mobility, permanent magnet DC brushless motor, which is 95% efficient. The batteries are Eagle Picher, silver-zinc. The steering is cable and bobbin. On the battery pod side, the two 20” wheels steer the vehicle. In addition all three wheels can be steered to allow yaw of the complete car to reduce aerodynamic drag during cross wind conditions. The suspension is leading and trailing link, with parallel wishbone on the battery pod side. Non-parallel, unequal length wishbones are used on the driver side with air/oil suspension at each wheel. The motor is direct mounted on suspension, unsprung. The total weight is 600 lbs.



Wind Tunnel Model of Viking XX, Solar Car

In the summer of 1990, Viking XX and Western’s VRI team competed in the GM Sunrayce and finished second overall to the University of Michigan’s Sunrunner. The Western team received GM sponsorship to the 1990 World Solar Challenge in Australia. GM paid all expenses for 8 of the 18-person team, shipped both the solar car and the 40' container containing the workshop, and provided satellite grade cells to make a new solar array for the Viking XX. This array was 15% more efficient than the previous array and produced 1.8 Kw, making it, according to tests by the U.S. Department of Energy, the most powerful solar car array in the world—and landing it on the cover of *Popular Science Magazine.*

Viking XX Solar Panels

The Viking XX was fifth in the World Solar Challenge behind the Swiss Car, Honda of Japan, University of Michigan, and Hoxan of Japan, all of which were one-person cars. Viking XX was first of the two-person cars.

Viking XX

I remember . . .

A "Working Honeymoon" with Viking XX

by Lisa Seal Christensen

After taking Bill Brown's advice, I married one of my father's former students (Dean Christensen) in the spring of 1990. The wedding happened to be about the same time that the VRI was gearing up to enter the "GM Sunrayce" with Viking XX. Dean was extremely interested in electric vehicles and the two of us spent hours in the lab assisting with the manufacture of the large solar array. When the dates of the competition were announced, Dean decided that the event would make a wonderful honeymoon trip for us. The Viking XX team had 40 members. Our job on this "working honeymoon" was to drive one of the four rented motor homes, locate and purchase needed car parts, buy food for the entire team, and attempt to get the various motor homes fixed when their systems broke down along the way.

This event was probably one of the best organized I had been involved with (considering the number of teams and the size of the teams). Dean and I flew down to Florida where we spent about five days seeing Disneyland and the other sites while the cars were getting ready for the race. My younger sister Georgia (then 12) also was on the trip, and part of our responsibility was to keep an eye on her while our parents were busy with the rally.

My first adventure on this trip was picking up the motor homes. I had never driven anything so big before, but the rental company would only allow drivers over the age of 25, so I was pressed into service to drive one of the beasts. The other fact that we learned later is that the RV rental place knew that they would not be getting these RV's back again (we rented in Florida and were returning to Detroit), so they gave us the ones that had problems. When we left the RV place we needed to find our way back to the hotel. We had a tourist map that was of little help when we came to the intersection of Peach Tree Rd. and Peach Tree Rd. and didn't know which one to take. After several wrong turns and some creative "navi-guessing," we finally made our way back to the hotel.

The tech trials were held at the Daytona Beach race track. It was all quite interesting to walk around and see the various cars and meet the other teams. It was very warm and humid; then at about 1:30 every day, the sky would open up and pour hard for about an hour. We found out why the track had 4 feet deep ditches. The ditches would fill up with water, and various over-heated team members would dive into them for a quick swim to cool off.

Another very cool thing that GM did on this event was to provide a catered dinner option for teams that wanted to buy a meal ticket. Every night of the rally, the caterers would come to the campground where the teams were all set up for the night, and set up tents and a buffet style dinner. The food was excellent, ranging from spaghetti to lobster, and everything in between. Breakfasts and lunches, however, were up to us to provide. Providing food for a team of 40 meant shopping at least every other day, because storage space in the RV's was very limited with 10+ people sharing each one. Sleeping accommodations were also cramped. Our RV, like the others, was laid out with a cabin in the back that had two side-by-side *twin beds. (My mom, sister, and I shared this small room.) Then there was a small bathroom/galley area. Next was the main cabin area, which contained a couch and dinette. But when those two items were expanded out for sleeping, they made a continuous bed the width of the RV. (Four people would share this sleeping area, and one would get the floor.) There was also a pull-down bed above the driver/passenger compartment that a lightweight team member could have; (Dean had that spot in our RV).*

On days that we didn't go shopping we were tracking down the local "Cruise America" dealer to get the worst behaving RV fixed; (Dean and I would rotate which RV we would drive to take in for service). Dean and I became quite adept at finding obscure items needed to repair the Viking XX in towns that we had never visited before. After we had done our "chore" for the day, Dean and I would catch up with the team at the next rest stop. The "Popular Science" issue with Viking XX on the cover happened to come out at the same time this rally was going on, so many people would come to the rest stops to see this "famous" car in person. It was also very cool to see all the people lined up along the roads and at the overpasses waiting for the cars to come by.

GM had also arranged for several interesting side trips for the teams to take after the race day was over. We were able to tour the Corvette plant, and we also got to do a lap at the famous "Brickyard" Indianapolis speedway. It just so happened that there was an official timer on duty the day of the race, and he qualified the speed of the cars as they came in to make their laps at the end of the day. Although it was not announced to the race teams that "official" speed records would be taken, it had been a sunny day, and the batteries in the Viking XX were well charged, so Dr Seal told the driver to open it up, and see how fast it would go. WWU later found out that Viking XX received the record for the fastest lap ever by a solar car on that track. I'm not sure, but I believe that record might still stand.

The race ended in Detroit, Michigan, to much fanfare and excitement. Western took first place in the two-person division and second place overall (UM took first place overall). This high finish got Viking XX a free ride to Australia, where it was able to compete in the World Solar challenge.

I remember . . .

VRI Deadlines and the World Solar Challenge

by Stan Miller

1. ***Career Influences****—My plans to major in business lasted until I enrolled in Dr. Seal's basic engine class the same term that I enrolled in accounting. I am now an engineer.*
2. ***Seal's Project Management****—Dr. Seal insisted that Western's first Formula SAE car, Viking X, move under its own power by a specific date, or we would not be joining the competition in San Antonio. It moved. Only a few feet. At 11:55 p.m. With a differential packed with peanut butter. That movement enabled us to get to San Antonio with a few days of running time and many modifications. Great rewards were a direct result.*

3. ***Knees and Compliments****—Ineptly, I managed to leave the flesh that belonged over my kneecap on the pavement in the middle of the Australian Outback. Three stitches and a wrap were all the nurse could offer (unless you count the pain killers). I was forced to take a day off from driving Viking XX. (Instead, I drove the chase vehicle and operated the clutch with my bad leg—when I used the clutch.) The day following my 'rest' day, I drove the solar car for six hours in two stints. By the end of the day, the knee was quite painful. Dr. Seal paid me a compliment by stating that I had gone above and beyond the call of duty. I am not sure he knew about the pain pills taped to the inside of the driver's compartment.*

Randy Weaver and Stan Miller, Viking XX Team Members
World Solar Challenge in the Australian Outback

In June 1991, the Viking XX was entered in the California Clean Air Race from Sacramento to Los Angeles. Because of the nature of this race, there would be more likelihood of good sunshine as well as a relatively short driving range each day and ample charging time. Viking XX was able to average over 50 mph on the freeway. During the actual race everything was as expected, although the team did get lost in L.A. on the last 40 mile leg of the course. However, they were able to retrace their route, finish a cumulative five hours ahead of the next finisher, and win the event

Chapter 8—The Hybrids

Viking Cars 21, 23, 25, and 27

Vikings 21 and 23

Following the success with Viking XX, Michael Seal decided to see if it would be possible to put the lessons learned in the previous 20 years of designing Viking cars into a prototype for the 21st century. Vikings 21 and 23 were funded by the Washington State Ecology Department, The Bonneville Power Authority, Puget Sound Power and Light Company, and supporters from throughout Whatcom County. Vikings 21 and 23, two hybrid parallel configuration vehicles, are the Vehicle Research Institute's solution to the desire of consumers to help the environment, yet not give up their freedom to travel by personal transport over long distances. The technology within Vikings 21 and 23 does not, of course, eliminate CO^2 production, but it does make it possible to reduce these emissions. The vehicles use presently available technology that requires a minimum of adjustment on the user's part. They were designed to have a 100 mile range on solar/electric power in the urban environment, and subsequently convert in use to a clean, fuel-efficient, internal-combustion-powered vehicle with an additional 200 mile range on compressed natural gas. In the beginning, the plans were to develop Viking 21 as a mock-up "mule" in steel to ensure the design would be able to incorporate all the necessary parts. But it soon became apparent that Viking 21 would become a complete running vehicle and that Viking 23 would be the composite chassis version of the design.

The solar/electric hybrid is a two-seat coupe with both occupants seated side by side. In the first irritation of Viking 21, the front wheels are powered by two brushless DC electric motors. The parallel configuration was chosen because parallel mechanical driveline efficiency is greater than that possible for a series hybrid. One disadvantage of a parallel hybrid is that a larger, more powerful internal combustion (IC) engine is required for hill climbing and maximum performance than would be needed for the series configuration. On the other hand, the parallel hybrid has the advantage that no large generator is needed to collect the IC engine power to charge the battery and run the electric motors. The electric motors provide regenerative braking when the brake pedal is depressed part way. A linear potentiometer controlling the level of regeneration is linked to the brake pedal. When a more severe level of braking is required than can be provided with regeneration, further pedal travel actuates the front and rear master cyclinders. Four aluminum calipers act on the 255 mm cast iron brake discs at each wheel. The calipers have a retraction system which ensures that the brakes do not drag when not being applied.

The rear wheels are powered by a Yamaha motorcycle engine through a 5 speed gearbox. A third electric motor also drives through this gearbox to provide additional power for climbing grades and starting acceleration. This car can be driven as a zero emission car in an electric mode or as a low emission car running on compressed natural gas in its internal combustion engine mode. All four wheels can be driven during ice and snow to enhance traction. Viking 21/23's internal combustion engine (ICE) drive to the rear axle was chosen to take advantage of the high inherent efficiency of a gear and chain drive transmission system when in ICE mode. The electric drive mode is used for nearly all urban use and accounts for about 90% of all trips.

In Viking 23 solar cells were mounted on the carbon fiber body panels and were designed to collect solar energy to store in the NiCd batteries while the car is stopped at a stop light or parked. Although theoretically a good system, in actual practice the solar cells broke easily, and the calculated power was never achieved.

The turbocharged, intercooled, fuel injected, natural gas engine in the first configurations powered the car at speeds over 50 mph. CNG provides a very clean, cold start. As no liquid fuel can adhere to the intake manifold, no enrichment is required. A multipoint electronic fuel injection (EFI) was used for natural gas. As Viking 23 exhibited the ability to travel 50 mpg. (21.1 Km/l), consumed at a constant 50 mph (80 Km/h), it is possible to travel more than 312 miles (500 Km) on the interstate freeway with one tank full of CNG. The first principal emission control was a three way catalyst strategy that provides very low NMHC and CO emissions and reduces NOx under heavy load. The new system, utilizing a zirconium dioxide oxygen sensor feedback loop fuel control allows use of a three way catalyst system that will meet the California ULEV standards in IC engine mode, and, of course, will qualify as a zero emission vehicle (ZEV) in electric only mode. The use of barrel throttle valves adjacent to the intake ports which promote high swirl at low throttle settings gives improved low speed torque, fuel economy, and emissions. The addition of proportional E.G.R. reduces NOx, and an electrically heated catalyst helps reduce cold start emissions. Extra air is introduced into the oxygen catalyst for further CO and HC reduction.

Viking 23's Carbon Fiber Chassis

Unique in the first irritation of Viking 21 were wheels that mount two tires on a single rim, much like a dual truck tire assembly. The two tires are very different, however, as the inner tire has a hard compound rubber and round section giving a very small contact patch. The outer tire has a wider tread patch and uses very soft high grip rubber. The wheels normally run at negative camber so the outer tire does not quite touch the road. During cornering, normal chassis roll causes the outer wheel to become perpendicular to the road surface, so the outer tire now grips the road securely, allowing higher cornering power. When the brakes are applied, a micro switch sends a signal to a solenoid high pressure valve which allows high pressure from the air pump to pressurize a central pneumatic system. A slave cylinder mounted at the outer end of each wishbone causes all four wheels to become perpendicular to the road, greatly increasing traction when stopping.

The Viking 21 "Mule" competed in the first Solar Electric Challenge for Pikes Peak. It won overall and was first in its solar hybrid class.

Viking 23, 50% of whose body was covered in solar cells, was completed in August 1994. This vehicle's chassis and body were constructed from carbon fiber. The vehicle was designed to keep its batteries charged through the solar cells mounted on its body. The solar array should have produced approximately 700 watts of power. However, due to cell damage and problems with cell leads, the solar array has never been a viable source of power for the battery. A battery charger is used to charge the batteries.

Viking 23

In 1998 Viking 23 was converted to run on reformulated gasoline instead of CNG, and a Daihatsu 993 cc, three-cylinder fuel injected single overhead cam engine replaced the Honda. Viking 23 was entered in the 1998 American Tour de Sol, which ran from New York to Washington D.C., and won its class for best fuel efficiency and the most tour miles.

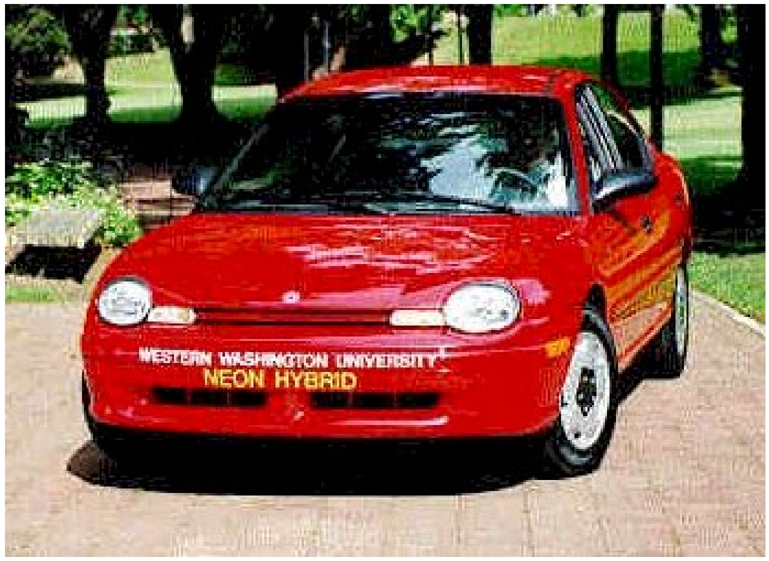
In 2001 a new body was designed for Viking 23 and manufactured from fiberglass; the two Unq brand motors were exchanged for one Unq brand HP electric motor. In this configuration, Viking 23 competed in Tour de Sol in 2002 and 2003. It was third in fuel economy and received the "most green car" award for student-built vehicle.

Viking 23 in 2003

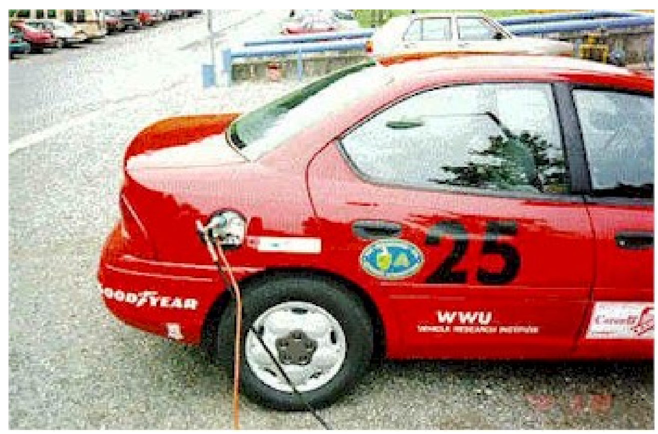
Vikings 25 and 27

Viking 25 is a stock Dodge Neon that was converted to an Electric Hybrid. This vehicle took first place honors for consumer acceptability, application of advanced technology, and range, as well as heating, air conditioning, and ventilation at the Hybrid Electric Vehicle Challenge in June 1995. The design focus was to be a good methane car with a relatively short all electric range to qualify for the competition. Viking 25 is also a parallel hybrid. The Neon uses a Morse silent link chain to electrically drive the input shaft of the Neon five speed transmission. Thus, it is front wheel drive in both the electric and ICE modes. The electric motor is a single water cooled 30 kW brushless D.C. Unq motor driving the front transmission input shaft at the outboard end. The Neon hybrid is intended to be a battery depleting hybrid whose sole means of charging is from the grid. The Neon uses 6 kW hours of Saft brand NiCd battery to give 144 volts at the motor. The two liter engine supplied in the standard Neon was modified to run on compressed natural gas by raising the compression to 14:1 and utilizing a modified factory fuel injection system with methane (CNG) injectors in place of gasoline units.

In May 1996 Viking 25 swept its class in the Tour de Sol road rally, winning best Neon conversion, lowest emissions, best use of materials, energy economy, range, consumer acceptance, and engineering design. In this configuration, the vehicle met the ULEV standards.



Viking 25 Neon CNG Hybrid



Viking 25 CNG Filament Wound Tank and Converted CNG Filler

Viking 27

Viking 27 was a Chrysler Mini van which was converted to run on propane. At first we attempted to run a liquid fuel injection propane system. That was not successful as it was difficult to get enough fuel volume. Therefore, we converted to gaseous propane. The propane was heated to provide the necessary pressure for the fuel injection. This vehicle did not prove to be very successful.

Chapter 9

The Thermophotovoltaic Car – Viking 29

I remember . . .

Working at the VRI was Like Being Part of a Family

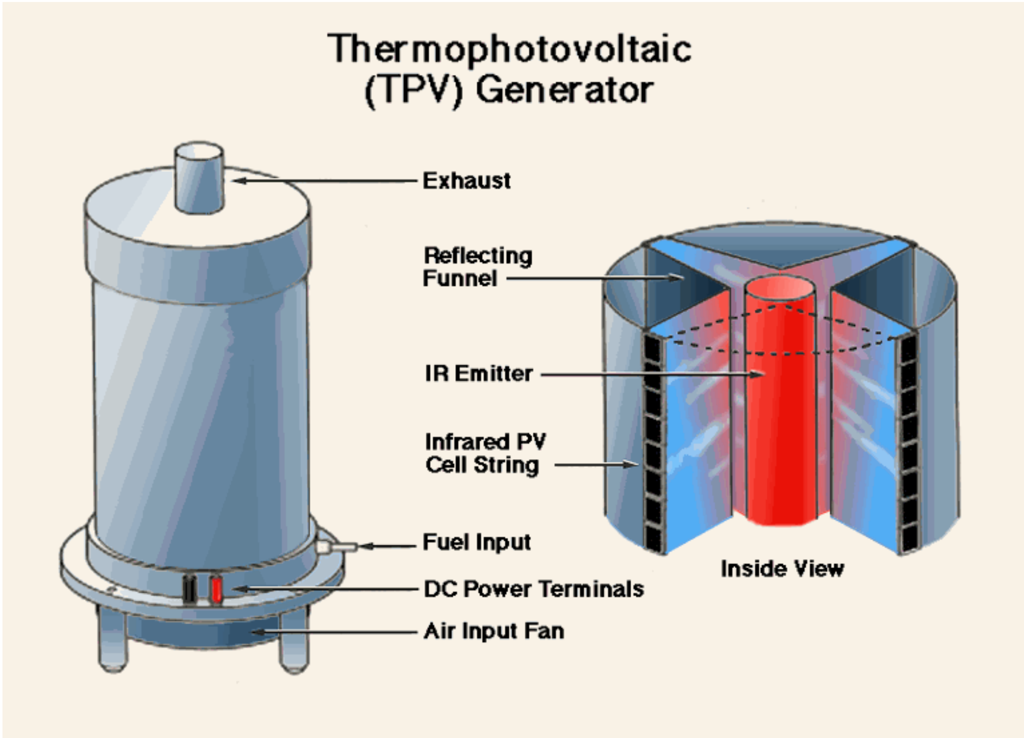
by William Connelly

One of the best choices I have ever made was working for Dr. Seal on the TPV research grant. It was my first job out of college, and I was eager to put my MET degree to good use. Floor space has always been a premium in the labs at WWU, and Dr. Seal was able to get more equipment into one space than any single human on the planet! As a freshly trained manufacturing engineer, my instinct screamed, "More space! These machines need more space! Just look at the ergonomics of it!" So I wasted no time and went straight to work moving everything around in the lab, trying to get at least a few feet of space in order for someone to work around each milling machine or workbench. But as soon as I had opened up any room on the floor, Dr. Seal would get another machine and move it in there! My constant rearranging must have driven Dr. Seal nuts. Fortunately, he was very patient so long as you didn't try to move something out the door. (Luckily, I didn't get "moved" out the door!)

But seriously, working at the VRI was like being part of a family, and I will always consider us one. I was sad when the grant came to an end and we all had to move on, but I will always remember TPV as one of the best jobs I ever had. Where I am in my career today is a direct result of taking that job with Dr. Seal and the VRI. Thank you, Dr. Seal. I wish you all the best in your retirement!

Thermophotovoltaic Generation of Power

The original thermophotovoltaic (TPV) concept was first proposed in the early 1960's. In the 1970's Kittl & Guazzoni attempted to build a practical TPV generator using low band gap cells and a selective emitter. The germanium cell performance was poor and the solid oxide emitter cracked with thermal cycling. This effort was abandoned. During the 1980's work shifted to fibrous rare earth oxide emitters and silicon cells. This work focused on the silicon cell, the ytterbia fibrous emitter, and on system modeling.

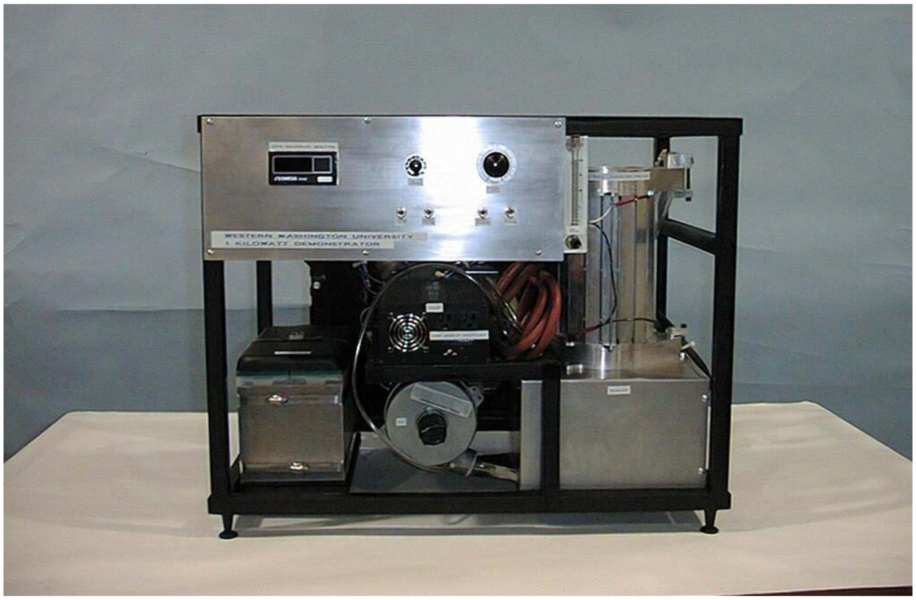


The Basic TPV Concept

In 1989 a Boeing group led by Dr. Lewis Fraas demonstrated a high performance, low band gap GaSb cell. Boeing and NASA developed this cell during 1990-1992 for space application. At the end of this period Dr. Fraas left Boeing to join JX Crystals Incorporated with the intent of developing TPV cells and systems. JX Crystals saw this low bandgap GaSb cell as enabling for practical TPV systems. Fraas approached Seal for help in the design and construction of a generator that would utilize the GaSb cells that JX Crystals was manufacturing. In 1994, Western Washington University and JX Crystals demonstrated that the predicted high cell power density could in fact be achieved with a radiant source operating below 1700 K.

Dr. Fraas with the First TPV Generator to Run a TV

A series of contracts, totaling over six million dollars, was submitted to the Washington Technology Center, the U.S. Dept. of Energy, and the U.S. Dept. of Defense. Over the next eight years the VRI and JX Crystals developed a number of generators, culminating in a stand alone field generator for the DoD and the Viking 29.

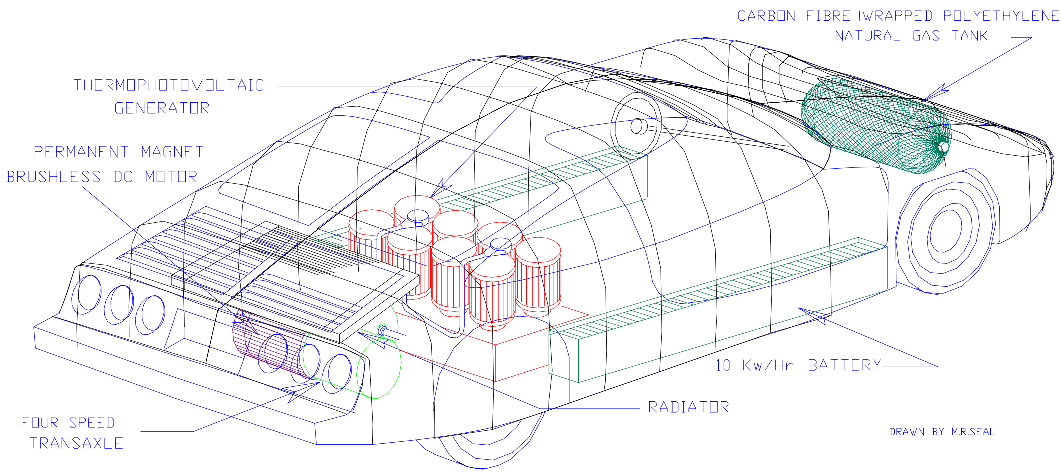


The Stand Alone Generator Developed for the DoD

Despite the best efforts of the VRI and JX Crystals, the high efficiencies of the GaSb cells projected by Fraas were never achieved, and without further funding the VRI discontinued any further research in the area.

Viking 29

Viking 29 is an experimental hybrid vehicle built to demonstrate the eight-cylinder TPV generator. This TPV generator was developed under a separate contract from the U.S. Dept. of Energy in conjunction with JX Crystals, VRI's industry partner in thermophotovoltaic development. The 10 kW TPV generator is cleaner and quieter than current generators with similar power. As a series hybrid electric vehicle, Viking 29 needed both a generator system (the TPV) and an electric drive system. Nickel cadmium (NiCd) batteries are used to provide load leveling.

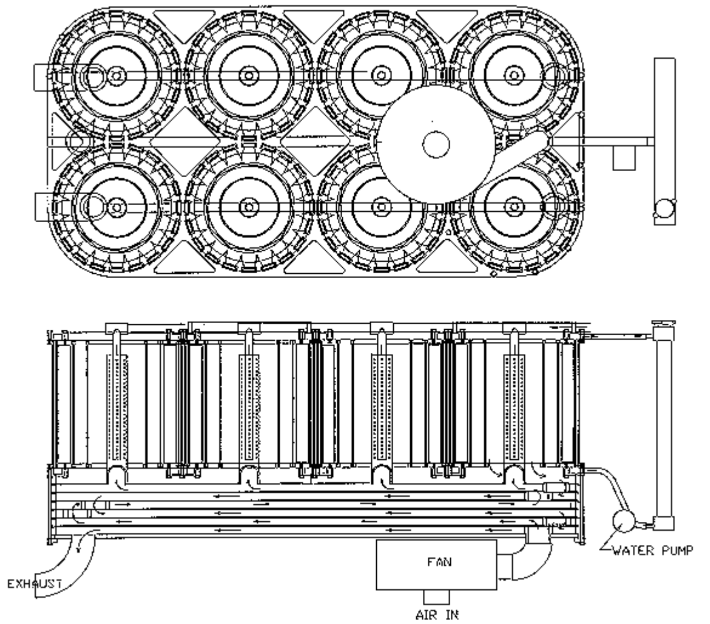


Viking 29 Layout

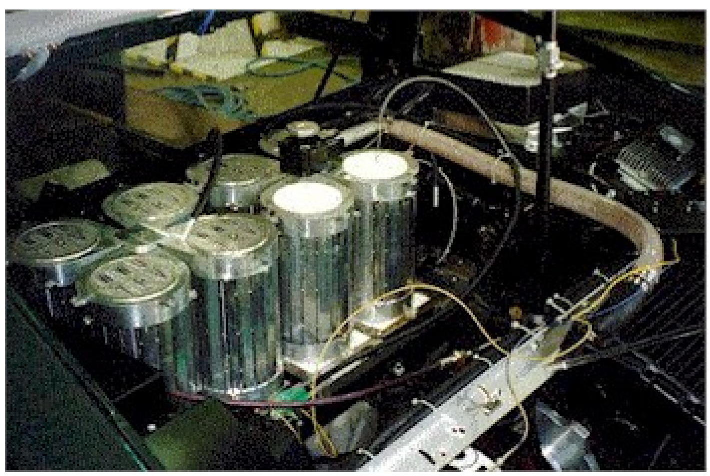
The Viking 29 TPV generator is a device making use of gallium antimonide (GaSb) photovoltaic cells, sensitive in the infrared range. These cells are arrayed around a fuel-fired infrared emitter. The configuration chosen is for a tubular silicon carbide emitter, mounted vertically above the recuperator.

GaSb cells surround the central emitter and are mounted on water-cooled heat sinks. The cells are wired in series strings of 19 cells. Axially mounted multiple quartz tubes break up the convective heat transfer loop while still allowing free passage of the active photons. A counter flow recuperator is mounted below each of the eight-cylinder units. The departing exhaust gases heat the incoming air stream to 1000 K before the fuel is admitted to the air stream.

The eight-cylinder unit is 432 mm long x 864 mm wide x 696 mm tall. The unit is designed to run at full power until the batteries are within 10% depth of discharge, whereupon the burner shuts off automatically. When the unit is running, the noise is similar to that of a desktop computer.



The First Design for an Eight-Cylinder Configuration to be Used in Viking 29



TPV 8 Generator in Viking 29

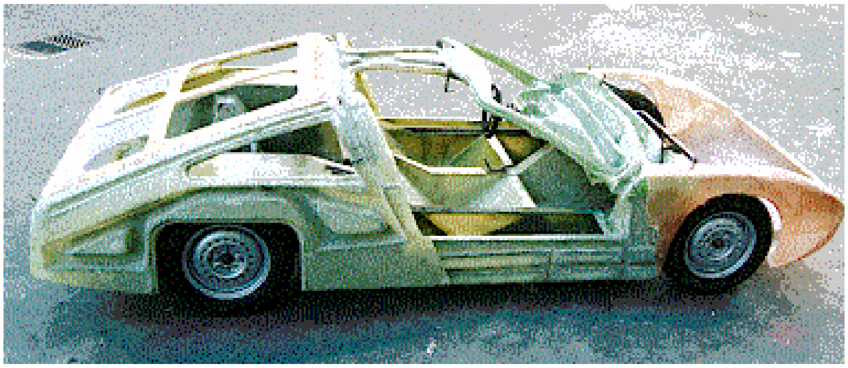
PV cells develop maximum efficiency at a specific point on the voltage-amperage curve. When the voltage rises too high, the current drops precipitously and vice-versa. Typically, maximum peak power trackers either buck or boost voltage from the input to output. The units made for the VRI by Xantrex not only stabilize the cell arrays at their maximum peak power but also raise the 32 V input voltage to 360 V needed to charge the battery.

The fuel tank for compressed natural gas (CNG) storage is mounted just ahead of the front suspension bay. A carbon filament wrapped, polyethylene lined fuel tank rated to 220 bar provides the fuel for the TPV system. A three-stage regulator reduces pressure to 1 bar when it is introduced into the combustors in the TPV burner unit. Air is introduced into the bottom of the recuperators by two squirrel cage fans, driven by pulse width modulated brushless DC motors. As the air passes through the counter flow heat exchanger, it is heated by the departing exhaust gases to near combustion temperature. Fuel is added just prior to the combustion zone. As PV cell temperature should not exceed 900^{o}C, the cells are cooled with bottom to top water flow driven by an electric pump. The water is cooled by two large single core radiators, which are mounted nearly horizontal at the rear of the car. Large ducted axial flow electric fans provide airflow when the car is stationary.

A 53 kW Unique Mobility motor and controller was chosen to power Viking 29. This motor offers 92% efficiency to the drive axle through most of the operating regime. The motor is mounted end on to a single dry plate clutch assembly running in ball bearings in a separate housing designed to remove all thrust loading from the electric motor. The clutch assembly is mounted end on to a transversely mounted, four speed, wide ratio transaxle mounted between the rear wheels of the vehicle. Drive shafts with inner and outer CV joints take the drive to the rear wheels.

Because the electric drive system running at 360 volts DC could provide a degree of risk in a chassis constructed of metal, a fiberglass composite monocoque structure was chosen for the vehicle. The battery boxes running along both sides of the car provide much of the torsional stiffness through the passenger bay. Many small "Allen head" screws are used to attach the tops of the boxes to the car to ensure chassis torsional stiffness. Removal of the covers for servicing is not difficult with a power screwdriver. The NiCd batteries used on the vehicle have a 10 year life expectancy and also have a very long maintenance interval. The batteries contain 10 kW hours at 360 V and power the 32 kW continuous duty, 53 kW peak power, brushless DC motor and controller.

For the prototype inner structural panels, a vacuum-bagged lay-up of biaxial roving in a vinyl-ester matrix was used to provide a high strength to weight ratio. As the outer skin requires a class “A” finish, surfacing matt and veil is used to provide a sandable surface before the outer skin is primed. All of the air ducts have been made structural to provide increased chassis stiffness



Viking 29 Monocoque Chassis

The chassis incorporates waffle panels to tie the inner and outer skins together. These waffle panels have been used throughout the car. The channels formed by the waffle shape are used for ducting to the cabin, heater, demister, and cabin ventilation systems. Ventilation ducting for batteries, motor, and motor controller is also accommodated this way. The motor and controller are water cooled and require air ducting to the radiator. Small brushless DC motors drive the fan and water pump for the electric cooling system.

The CNG fuel tank is used as a reaction bulkhead for the aluminum honeycomb deformable structure in the nose of the vehicle. Although Viking 29 was not tested in a barrier crash, occupants should be able to survive a 56 km/h barrier crash. The VRI previously crash tested Viking VI, which utilized a similar configuration. The stiff battery boxes provide substantial side crash protection by forcing the impacting car to deform its nose structure.

Throughout the vehicle, carbon fiber reinforcement has been used only where space constraints do not permit enough stiffness with “S” glass reinforcement. Semi-gull wing doors are used to provide improved access made necessary by the relatively wide and deep doorsills, which contain the batteries. The doors use a hidden hinge ball joint at the front, lower corner of the door and a very small external hinge point at the upper, inner windshield corner. As the diagonal, air inflatable, passive restraint safety belt attaches to the door, it is necessary to provide a high strength locating pin where the door edge connects to a strong point in the door surround. The bumpers of the vehicle incorporate a stiff and sturdy fiberglass reaction beam and a sacrificial bumper skin that is easily and inexpensively replaced in the event of damage.

Placement of headlights has always been a problem on the Viking series of streamlined cars because the low and sloped front body section does not provide a mounting position for conventional lights that meets the minimum legal height required above the road surface. In the past, pop-up headlights were used which degrade vehicle aerodynamics. To reduce drag, mounted headlights behind the lower edge of the windshield have also been used. As the federal standard minimum height has been reduced from 610 mm to 560 mm, and as credit card- sized, sealed beam headlights have become available, the headlights on Viking 29 are mounted under clear acrylic shields in the front fenders. The centerline of the composite headlight meets the 560 mm minimum height with the low beams mounted above the high beams to ensure minimum dazzle on low beam as the headlights are dipped for oncoming traffic. The rear lights are also lightweight sealed units mounted in round tunnels just above the rear bumper.

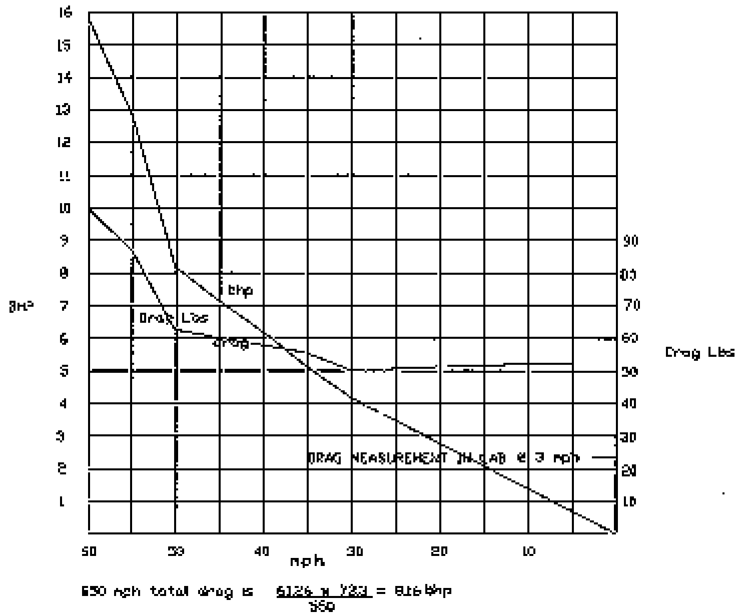
Only the driver's seat adjusts for tilt and front to rear position. The seat pivot point is well forward of the driver's H point. The H point rises as the seat is tilted forward, which raises the shorter driver's eye height and simultaneously brings the driver's shorter arms nearer to the steering wheel. Instrumentation consists of a speedometer and tachometer mounted in a binnacle behind the steering wheel. The ammeter, voltmeter, and state-of-charge meter are mounted in a multi-function instrument in the center console. The CNG fuel pressure gauge is also mounted in the center console.

The interior surfaces are finished in polished carbon fiber along with carpeting. The seats are finished in leather. The gearshift lever is situated on the central tunnel and is connected to the transaxle with two push pull cables. The handbrake lever is mounted under the instrument cluster and actuates the rear disc brake calipers with pull cables. The heater unit mounts ahead of the toe board and behind the fuel tank. This unit also provides hot air to the demister and face ducts through structural passages that are part of the monocoque structure.

Short and long arm wishbone suspension links have been fitted at the front and rear of the vehicle. Direct acting coil-over dampening units have been utilized at all four corners. Front and rear anti-roll bars provide easy tuning of oversteer-understeer. Four non-power assist disc brakes provide short stopping distances with low pedal effort. To reduce lost motion in the brake system, the master cylinder pedal assembly is rigidly mounted to a stiff wall section provided in the unibody structure. Teflon lined, steel armored, flexible brake lines remove another source of lost motion due to swelling of flexible lines (when under pressure). Minimum loss of motion because of flexible components means a high multiplication factor can be used without bottoming the brake pedal. An adjustable brake bias bar is used to tune the front/rear braking ratio. There is a knob mounted on the dashboard that provides easy adjustment of the bias bar.

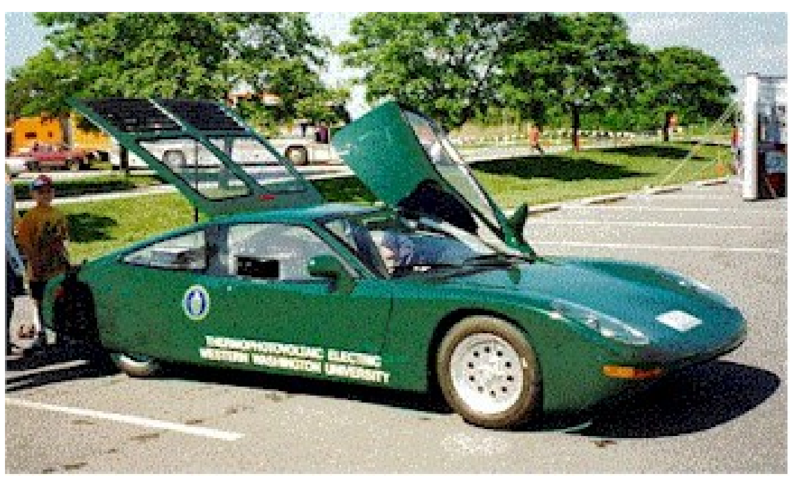
To reduce aerodynamic drag, the body shape was derived from a series of wind tunnel models developed at the VRI during the last several years. The CxA for the model chosen is .25 and the frontal area is 1.34 m^2 for a CxA of .338.

As rolling drag is strongly dependent on vehicle weight, battery size becomes an important determinate. A 10 kg increase in battery mass will probably result in a 50 kg increase in vehicle weight as the supporting structure, suspension, brakes, and motor must be increased to provide equivalent performance. If the battery is too small, the electric motor will not be able to draw full power at 75% depth of discharge, and performance will suffer as the motor can draw up to 53 kW from the system. As the TPV unit can only supply 10 kW, 43 kW must then come from the battery. Fortunately, the NiCd batteries used in this car maintain high power density to 90% DoD. Therefore, it was decided to use 10 kW hours of battery at a weight of 270 Kg.

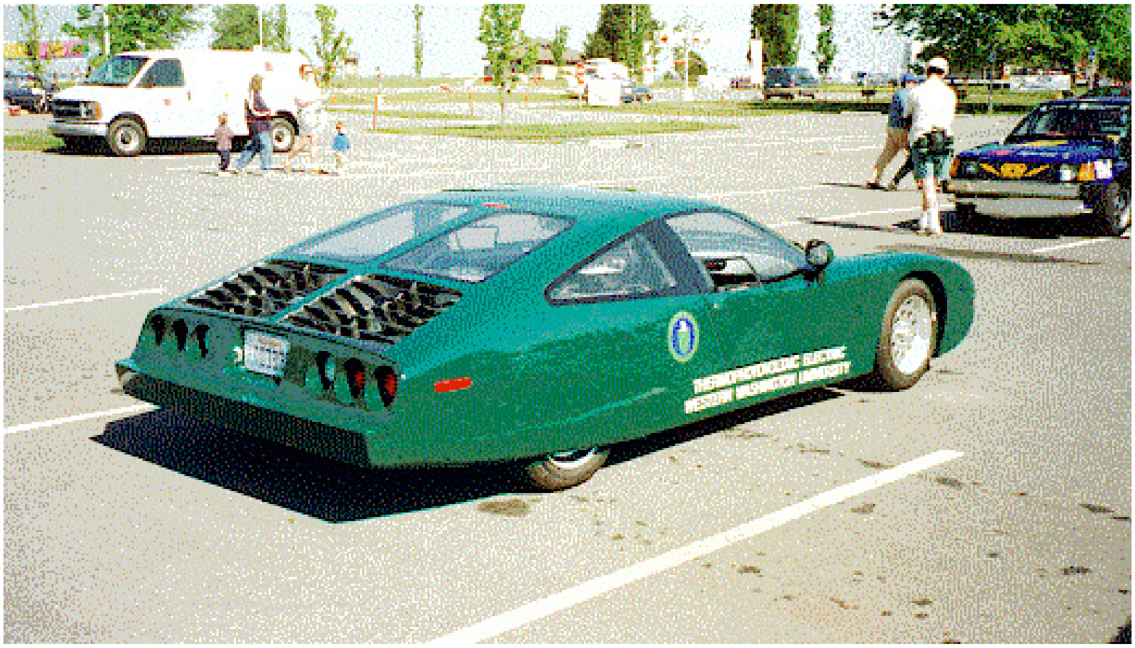


Viking 29 Projected Power Requirements

The TPV generator used as an auxiliary power unit (APU) in the Viking 29 automobile demonstrates that an extremely clean and quiet method now exists to continuously charge the on-board batteries for a series hybrid car. Unburned HC and CO emissions are low enough to qualify as a virtual ZEV, but NOX emissions require a reducing catalyst to reach virtual ZEV standards. Further work needs to be completed on the TPV 8 generator to optimize its performance. Matched emitters and improvement of view factor for the PV cells to increase power density would result in improvement to the overall system efficiency. As further funding was not available to further develop the efficiency of the TPV generator system, this form of power generation is not currently a viable source of power for vehicles.



Viking 29 – Front View



Viking 29 – Rear View

Chapter 10

The Student Teams – Formula SAE and Mini Baja

Sponsored competitions of The Society of Automotive Engineers (SAE)

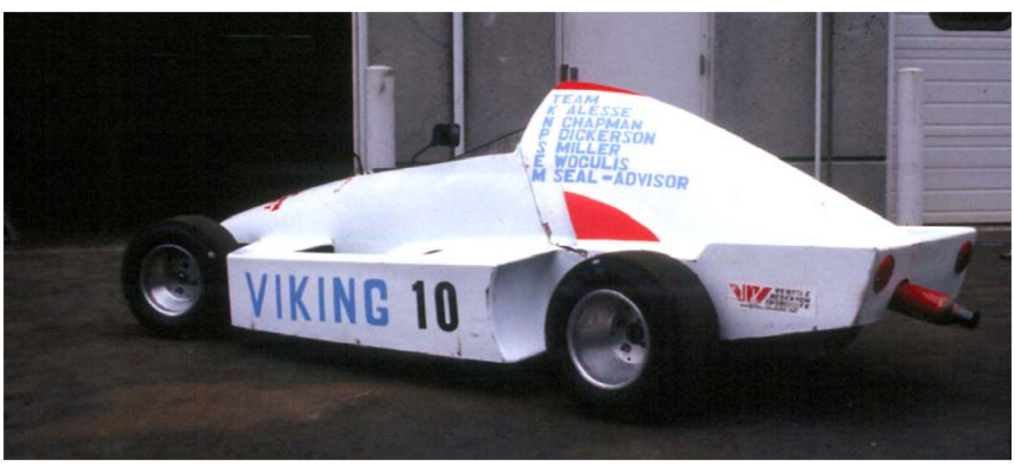
The SAE sponsors a number of competitions for engineering students each year. These competitions are designed to combine what students have learned in their engineering courses with a real world project that they complete from the beginning to the end. Being a member on one of the teams shows a strong interest in vehicles and also brings out the best engineers who go beyond the normal engineering curriculum. It gives students the opportunity to learn skills such as time management, teamwork, management of schedules and budgets, and delegation, areas that are not usually part of the classroom. Students from the VRI have competed in three different types of these competitions. The “Supermileage,” the “Formula SAE,” and the “Mini Baja” have all been entered.

The Supermileage competition provides engineering and technology students with a challenging design project that involves the development and construction of a single-person, fuel-efficient vehicle powered by a small four-cycle engine. Students have the opportunity to set a world fuel economy record and increase public awareness of fuel economy. Engines are donated by Briggs & Stratton. Students from the VRI entered this competition back in successive years in the early eighties with several streamlined vehicles. They also converted a Briggs and Stratton engine to a radial 4 valve configuration. By using a Briggs and Stratton crankshaft and sleeving the block to fit a Honda 50 cc piston, the team was able to make a long stroke engine. They also built an “F” head and an overhead 2 valve bathtub chamber conversion. The best mileage that the teams obtained was a little over 1000 mpg at a time when the University of Saskatchewan was getting over 2000 mpg. Interest in this competition declined at the VRI when students became interested in entering the Formula SAE. The final vehicle was converted to the VRI’s first solar car.

Western's Supermileage Vehicle

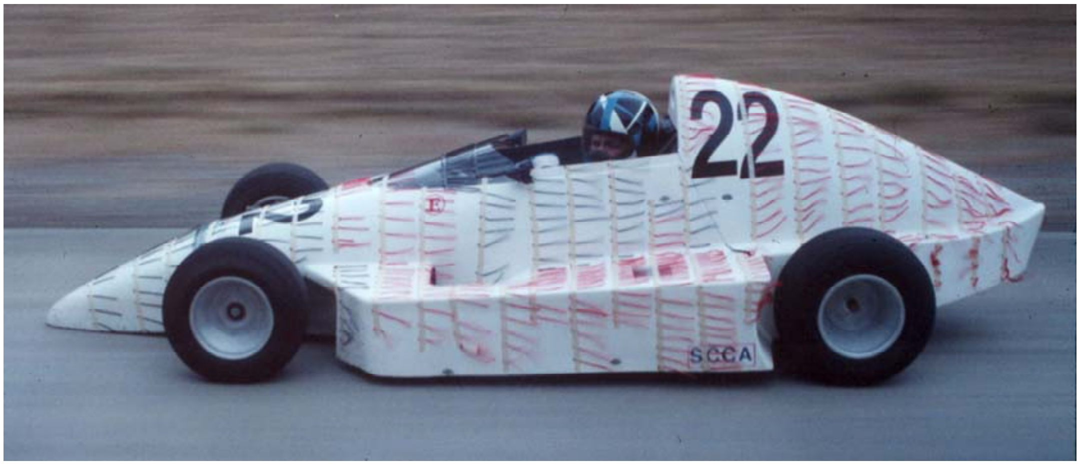
For the Formula SAE competition, students design and fabricate small formula-style race cars, and then compete with them. Restrictions are placed on the car frame and engine, so the students' knowledge, creativity, and imagination are tested. To add another dimension to the challenge of engine design, four-cycle engines up to 610 cc can be turbocharged or supercharged. However, all engines must pull all of their intake air through a 20 mm restrictor. The vehicles are judged in three different categories: static inspection and engineering design, solo performance trials, and high-performance track endurance. The first Formula SAE vehicle designed at the VRI grew out of a Formula 440 design done under contract to the Race Cars of the Future Company. Students saw the potential of this car and redesigned the vehicle to meet the Formula SAE rules.

The Viking 10's claim to fame was a peanut butter differential. This was made from two Geroter pumps installed back to back so they pumped into each other. When the two used pumps were filled with any conventional hydraulic fluid, they leaked too much. So they were filled with chunk-style peanut butter. However, when one accelerated the car out of a tight turn, the car smelled like roasted peanuts!



The First VRI Formula SAE

Viking 10 was modified and rebuilt to become Viking 22. It was the first car in the Formula SAE competition to have four-wheel steering. This feature was copied the next year by a number of schools, including the University of Washington.



Testing the Aerodynamics of Viking 22

Some years later Viking 24 was designed. This car was notable for using a spool rear axle to replace the differential. It also used ten degrees of castor to lift the inside the rear wheel and allow the car to "turn in" well. The car won the Goodyear performance award and placed fourth overall.

I remember . . .

A Pirouette in Blue

by Eric Leonhardt

Viking 24 had just returned from competing in the Society of Automotive Engineers' Formula SAE event. We were a bit depressed because one of our front wheels had fallen off during the event. To pick up our spirits, we repaired the car and challenged the University of Washington team to a series of driving events in the U.W.'s parking lot. My fiancée's father, Jim Buckley, brought a dazzling blue 1958 Porsche Speedster replica, complete with a tube frame chassis, coil-over adjustable Koni shocks, and 2.2 liter Porsche flat six engine. Jim let Dr. Seal borrow the vehicle to test it in the parking lot. As I was talking to Jim, a loud screech erupted from the parking lot. I watched with trepidation as the blue car spun, completing a full pirouette. I kept talking. Jim's back was turned to the car. Fortunately, Jim has a good sense of humor. He is now my father-in-law. As for Dr. Seal, over the past ten years I have enjoyed every minute that I've had the opportunity to talk with him.

I remember . .

"How Fast Will It Go?"

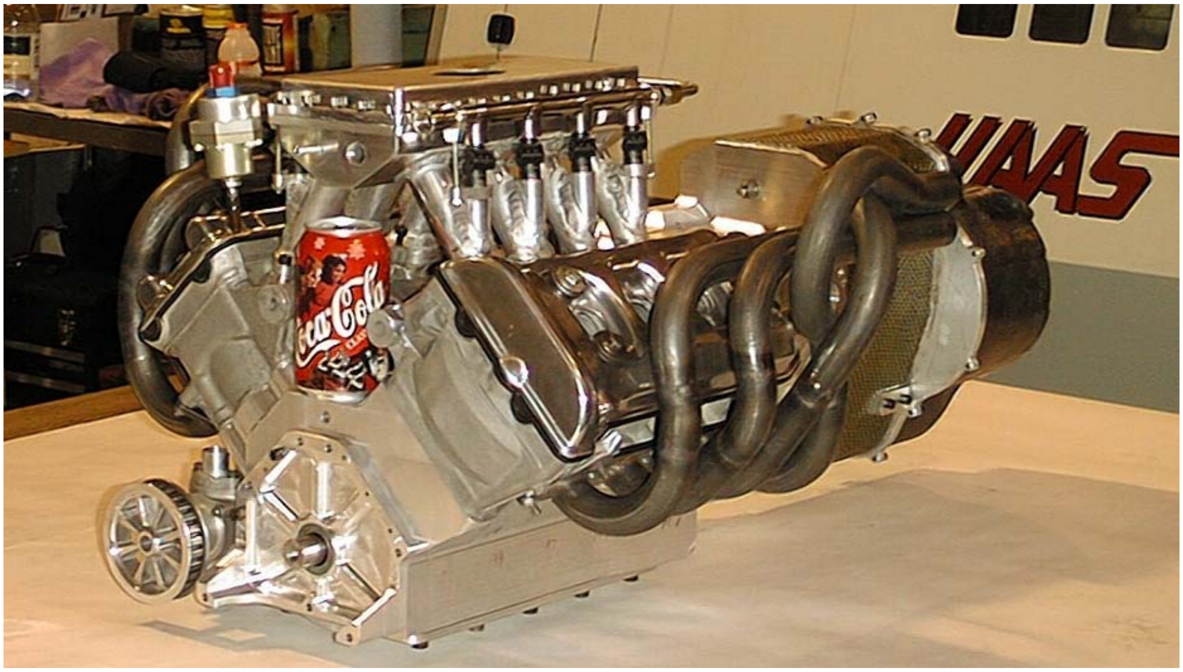
by Tim Roddick

Having spent a few moments reminiscing about time spent at the VRI, I realized that there are indeed a few stories from those days that might not strictly qualify for the compilation, but that do indeed give a flavor of the atmosphere there. The following is such a story.

Having partially completed one of the Formula SAE cars (Viking 24, perhaps?), we set off to Paccar (who had kindly offered to let us test at their Mount Vernon facility) to do a little development work. Off we went, trailer in tow, with Dr. Seal to follow with one of the (lucky!) students in Dr. Seal's then-new, third generation Mazda RX7. We didn't see much of Dr. Seal until just as we arrived at the gates of Paccar's facility. After parking the tow vehicle, we began the process of unloading the Formula car. While this was underway, a couple of us sidled over to the red RX7 and started asking questions regarding Dr. Seal's recent purchase. One of the questions, the ubiquitous "How fast will it go?" was finally asked, to which the reply came, "Well, we know it'll do at least 140." A brief silence was followed by a mumbled utterance of "We sure do...." from the ashen-faced student who had ridden down with Dr. Seal!

Viking 26 was the first carbon fiber twin tube "rocket launcher" car that also made extensive use of CNC parts. It, too, won the Goodyear performance prize. Viking 28 had a chassis similar to Viking 26. For the first time the team designed and made its own inside out front disc brakes and double disc brakes at the rear. The Honda 600 cc motor cycle engine was turbocharged. This vehicle was taken to England to compete in the European Formula Student Competition in Birmingham where it finished third overall and won the Henry Royce Gold Medal for student engineering and craftsmanship.

Viking 30 was the most ambitious Formula SAE car attempted by any team. The V8 engine and six speed transmission on Viking 30 are two items that make this car stand out. The engine block, crankshaft, connecting rods, and transmission case were designed and manufactured at the VRI by the FSAE team. The engine block was CNC machined from aluminum. The heads were taken from a Kawasaki 250 cc 4-stroke motorcycle engine that made peak power at 19,500 rpm. The six speed transmission case was machined in house out of aluminum, and featured internals borrowed from a Honda 600 cc F1 motorcycle. The transmission and engine are fully stressed members of the chassis and feature mounting points for the suspension.



The Student-Designed and Student-Machined V8 Engine

The chassis is based upon previous WWU carbon fiber tube designs with integrated CNC machined aluminum bulkheads. Viking 30 is the third evolution of this design and has evolved into a monocoque hybrid, based on knowledge learned from previous generations. The chassis was constructed using the cut and fold technique developed in Formula 1 racing. The advantages of this design are rapid production time, no autoclave required, low overall chassis weight, and high torsional stiffness. Western is one of only a handful of universities to make any type of monocoque chassis. The chassis is very advanced when compared to the typical steel tube frame of other Formula SAE competitors.

Viking 30 (65 is the Competition Number)

Viking 35 features a unique chassis. The design has its roots in previous FSAE cars from the VRI, but has progressed substantially. It uses two 6 inch diameter carbon fiber tubes and panels made of carbon fiber and Nomex honeycomb for the main structures. Hollow aluminum bulkheads tie everything together. The result is a chassis that is very lightweight and stiff. These two factors are critical for a racecar. In an effort to reduce weight, the students made extensive use of carbon fiber and CNC machined aluminum.

The car is powered by a heavily modified engine from a Honda motorcycle. The students added a fuel injection system, a turbocharger, and a dry sump oiling system. The fuel will be E85, a blend of 85% ethanol and 15% gasoline.

Viking 35 shares many of the same features as the older cars, but everything is new. Some Viking 35 student-designed and student-built parts include these: steering rack, brake calipers for "inside-out brakes," brake master cylinders, shocks, CV housings, differential housing, drive shafts, carbon fiber suspension uprights, and CNC machined aluminum A-arms.

<u>Performance goals for the Viking 35 are as follows::</u>
0-60 mph time: under 3.8 seconds (Dodge Viper Territory),
Lateral acceleration (cornering ability):1.5 g (The Ferrari Enzo gets about 1.03 g),
Quarter mile time: under 11 seconds.

Unfortunately, none of the goals were met. When the car was taken to the 2004 Formula SAE competition, the engine blew up during a practice run. It was rebuilt with the loan of parts from the University of Idaho, who had a spare engine. The students succeeded in getting the new engine installed in time to compete in the endurance race. Viking 35 completed two laps before it stopped; the driver was unable to restart it. However, the team members who will be continuing next year already have plans to build a new and improved version for the 2005 competition.

History of the SAE Mini Baja Race Cars at the VRI

The SAE Mini Baja team began in the fall of the 1999 school year with a small group of younger students whose backgrounds were in off-road motor sports. As the VRI had not previously been involved in the Mini Baja Collegiate Design Series, the students had to convince Dr. Seal to include such a race team in the VRI.

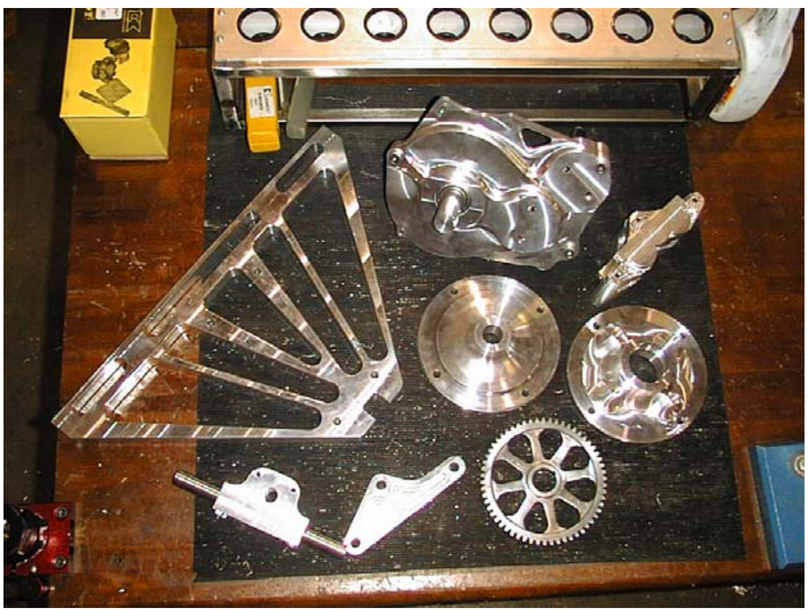
In the 2000-2001 school year, the first car, Viking 33, was assembled by the team. In the spring of 2000, the team had ambitiously entered the Midwest competition in Milwaukee, Wisconsin, which is based upon a motocross course. Unfortunately, the team failed to complete the car on time. That notwithstanding, the team placed 93rd out of 120 teams, based upon their written reports. Viking 33 was finally completed for the 2001 Midwest competition, where it placed 52nd out of 120 entries. This showing was certainly not bad, as Viking 33 was the first car of this type that we had ever made. Viking 33 featured the rules-dictated Briggs & Stratton 10 horsepower engine. Power was transmitted through a CVT (Constant Velocity Transmission) and then through a double chain and sprocket reduction system.

Much of the rest of the car was made with whatever was available around the VRI. Because this new type of car and its competitions were unlike previous VRI cars, the team had to struggle to raise funds.

Briggs & Stratton 10 hp Engine

After having learned from the first Baja car, most of the team stayed on and began designing a new car, Viking 34. It was designed to compete in the spring 2002 Midwest competition in Milwaukee, Wisconsin. With this car, the students made an extreme effort to utilize all of the technology that was available to them in the VRI. This car featured the same Briggs & Stratton 10 horsepower engine and CVT, but this was where any similarity to the old car ended. Team members designed and machined a double reduction gearbox that was a stressed suspension member. The suspension was a parallel, unequal length, double A-Arm configuration at all four corners. However, a feature that is unique to the VRI car is that the rear lower suspension arm is the drive shaft. Everything on Viking 34 was modeled in CATIA, and parts were CNC machined or custom fabricated, with the exception of the obvious items such as wheels and tires. At the Midwest competition, this car placed 44th out of 120 entries.

Viking 34



Mini Baja CNC Parts

Mini Baja Student Designed and Fabricated Gearbox

Mini Baji CVT

With the experience gained from Viking 34, the members of the team who had not graduated returned to build Viking 36 for the 2003 West Race. As the West Race course runs primarily through woods on un-manicured terrain, the new car had to be designed for much harsher conditions.

Mini-Baja Course

Many of the same features and part designs were carried from Viking 34 to Viking 36. The team's goal was to begin implementing a design evolution process for future teams to follow so that succeeding years' teams would not have to start over from scratch. The 2002-2003 team placed a far greater emphasis on testing, tuning, and development. The suspension was refined, and the drivetrain was redone in order to maximize the power output by the engine. After all of their efforts, the team placed 42nd out of 113 entries in Provo, Utah, in the midst of every kind of weather condition short of a tornado.

Viking 36 at Home

Viking 36 in Competition

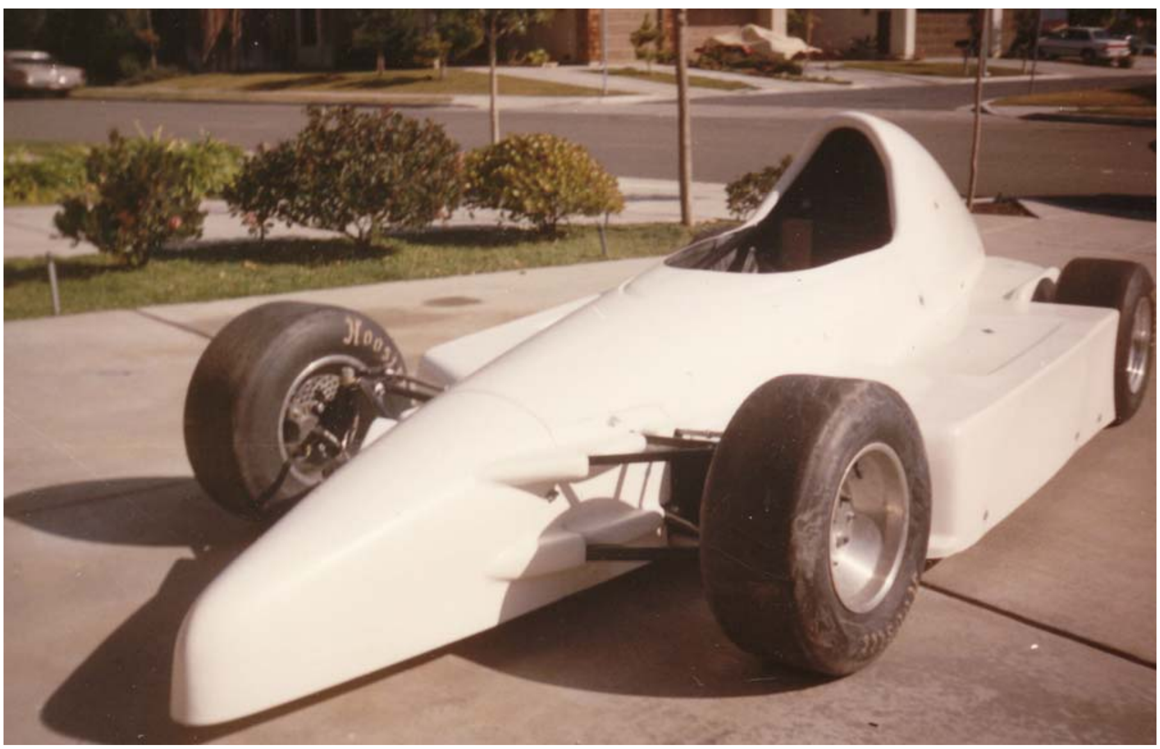
For the 2003-2004 school year, the VRI decided to run two cars in the West competition in Portland, Oregon. Viking 36 was to be redone and brought back as a redesigned entry, and a new car, Viking 37, was to be constructed in parallel. The team modified the suspension in Viking 36 and tuned its drivetrain. In addition, there was a great deal of skid plating and shielding added to protect it from rocks and mud. The engine's intake was also rerouted to avoid drowning the motor in water. All of these modifications were designed into the new car as well. Viking 37 was to be designed around a long-travel suspension, featuring nitrogen sprung shocks with 14 inches of travel in the front and 12 inches of travel in the rear. Viking 36 placed 13th out of 93 entries, which was the best that the VRI had ever done in the SAE Mini Baja Design Series. Viking 37 placed a respectable 45th.

Chapter 11

Engines and Other Miscellaneous VRI Projects

Formula 440

In 1987 Dan Hanley of Racecars of the Future asked the VRI to design a new Red Devil Racecar body for him. Wes Williams and Michael Seal took on the task and developed a wind tunnel model that produced substantially less drag than the model for the old Red Devil. Wes crated a full sized plug and molds for the new body shape. When the chassis arrived from Don Hanley, it proved to be somewhat larger than the drawings we had been given, and the body didn't fit. When Dr. Seal examined the chassis, he determined that a redesign would provide a much more effective suspension. Don Hanley agreed and made another example to Seal's drawing. The resulting car was very successful as it won the national championship in 1989 and sold in great numbers for a racecar. Over the years, several students have done redesigns for Dan.



Formula 440 Designed for the Red Devil Racecar Company

Viking 31—A Streamliner

Viking 31 is the vision of Marlo Treit, who approached Dr. Seal with a rough idea for a land speed, piston-powered vehicle to set a 550 mph record. Dr. Seal assisted in the design, shape, and size of this project; the VRI provided all of the wind tunnel time and information to bring about the final shape. Dr. Seal's ability to think outside of the box was invaluable. Jim Hume of Sedro-Woolley, Washington, is doing the chassis and the body. Marlo Treit is constructing all of the mechanical parts. The power is by two, 510 cubic inch, supercharged, Hemi aftermarket, V8 engines. They each produce 2500 hp, using alcohol fuel. The superchargers force the fuel mix in at 45 pounds pressure. The vehicle is 4-wheel drive and has two, four speed planetary transmissions and much modified quick change assemblies in both the front and rear drive units.

The VRI students and staff have made numerous field trips to Hume's Sedro-Woolley shop to inspect Viking 31's progress. Without the assistance of Dr. Seal and WWU, the success of this project would not be possible. Dr. Seal's experience and hands-on knowledge of Land Speed Racing is unmatched in the high speed low drag community. Testing will begin in 2005. Thanks to WWU and Dr. Seal at the VRI, Viking 31 will become a reality. It has been called by many in the land speed community, the best researched and most purposeful wheel driven auto to be constructed in decades.

Viking 31 – A Bonneville Streamliner Aerodynamic Model
(Model Wind Tunnel Testing Done at the VRI)

Propane Conversions

From the beginning, the VRI has modified the engines in its vehicles to meet the needs of various competitions. The VRI has strived to improve standard engines and power trains to run on alterative fuels or to improve fuel economy.

Vikings I, II, III, and 27 all used student-developed propane conversions. The first system developed for Viking I (a 1969 Toyota Corona) utilized an Impco regulator and carburetor designed for a fork lift truck and a steel propane tank from NW Propane Company. Dale VanderYacht was extremely helpful in this endeavor, giving freely of his time, expertise, and hardware to make the conversion successful. This engine was turbocharged using a turbo from an F-85 Oldsmobile. Even though an intercooler wasn't fitted, Viking I won the acceleration event at the Urban Vehicle Design Competition. Because the VRI had no emission test equipment in 1971, the engine could not be tuned for good emission numbers.

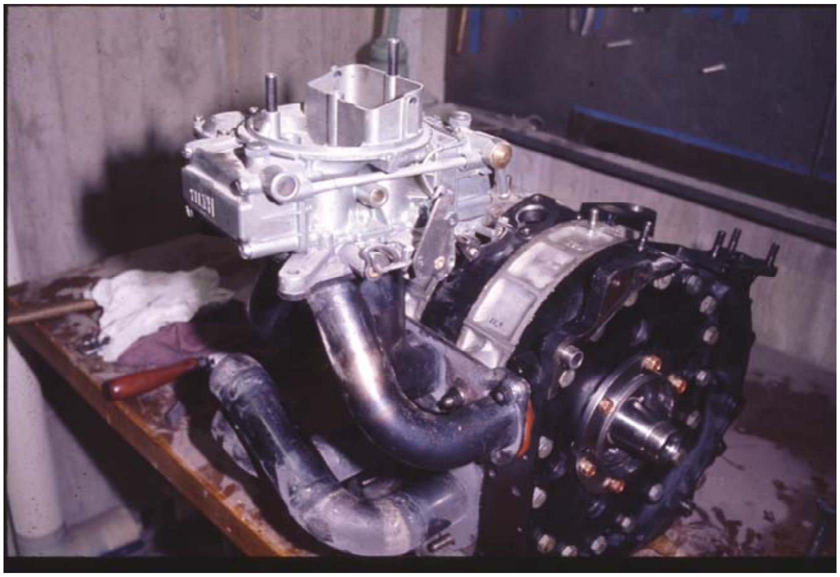
To tune Viking II a non-dispersive infrared (NDIR) HC, CO unit was acquired by the VRI. We discovered that the fork lift carburetors did not provide good mixture control across the engine range. A three carburetor progressive setup was tried and proved to be even worse for emissions, but it did produce more power.   Bill Brown and Michael Seal collaborated to design and make a superior single carburetor which was good enough to post the lowest emission values in the SEED Rally in 1974. The engine used was an 1100 cc Subaru Star Boxer four-cylinder engine. The ignition curve was reworked by changing springs and limit stops inside the distributor. The compression ratio was increased to 12:1, and a resonant ram induction and exhaust system was created for this engine. To reduce engine rpm at 50 mph, we made 400 mm wheel rims to fit low rolling drag Michelin tires. This combination was good enough to provide 59 mpg on propane fuel (74.5 mpg gas equivalent). For subsequent events, a five speed was made from two four speed transaxles. A housing was cast to fit on the back of the gearbox to house another third gear and synchromesh upside down to give an overdrive top gear that provided further fuel economy improvement.

When it became apparent that propane was not going to be the fuel of the future (world wide supplies are not sufficient), the VRI stopped research on this fuel until Viking 27. At that time Chrysler donated a mini van to convert to propane, and the VRI then entered it in their sponsored competition. Viking 27 placed fifth.

Wankel Rotary Era

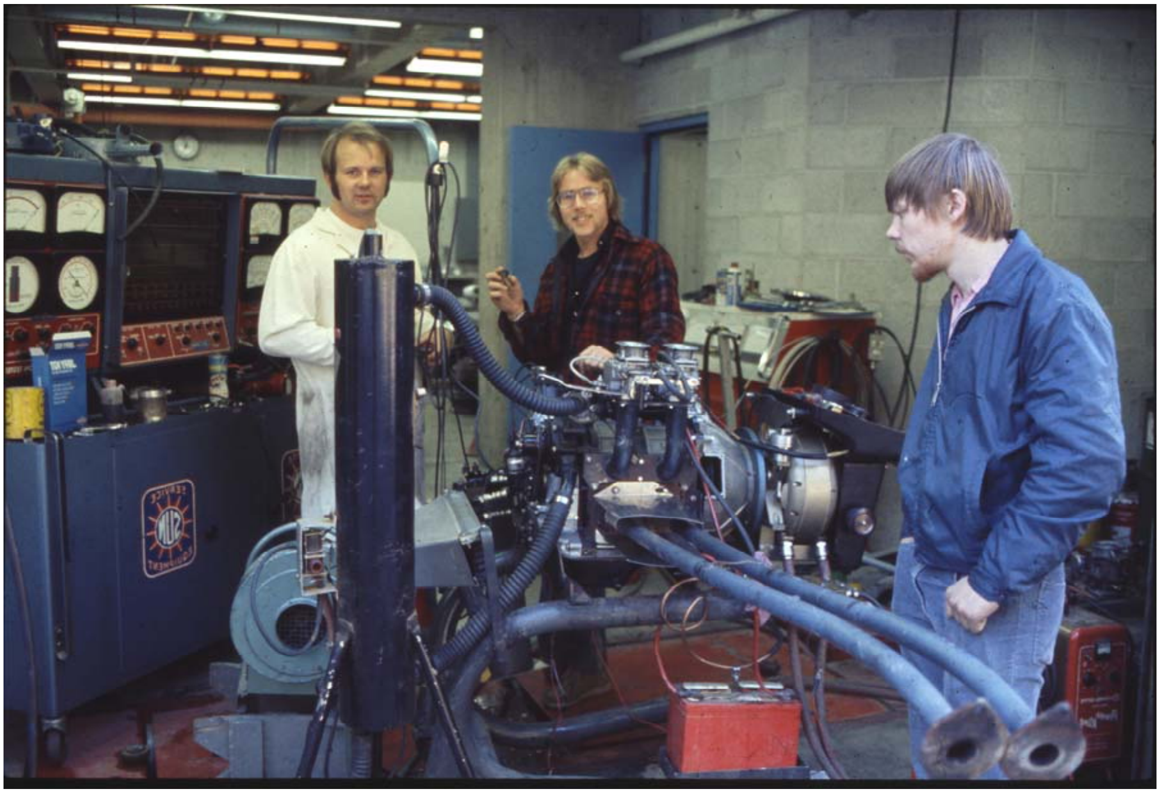
In the 1960's when articles about them began to appear in the auto enthusiast magazines, Michael Seal became interested in Wankel engines. As it was not possible to purchase a Wankel engine at this time, Dr. Seal designed and built a 100 cc water cooled experimental Wankel engine. The most difficult part to machine was the epitrochoidal housing at the center of the engine. Bill Brown and Dr. Seal collaborated on converting the Bradford lathe into an epitrochoid cutting machine. The housing was cast around an iron liner which was forged into an approximate epitrochoid. The casting was machined flat in the lathe and mounted in a four-jaw chuck. A splined drive, made from a 10- spline Chevy input shaft to a gearbox and a matching hub from a clutch, drove a 2:1 overdrive pair of spur gears which, in turn, drove an eccentric shaft that had an offset equal to the desired radius of eccentricity. This eccentric shaft then drove a lathe cutting tool that was mounted in a compound rest. This compound rest had been remounted on an angle plate so that it sat vertically above the cross slide which had the drive screw removed. The tool bit rotated at twice the engine speed so that, as the tool advanced into the work, it cut a true epitrochoid.

The first try at tip seals for the engine used phosphor bronze material, but the material proved unworkable as wear began as soon as the engine started. A letter to the president of Toy Kogyo, a supplier for Mazda, yielded an offer of sintered carbon-aluminum material that they were using on their experimental Wankel rotary engines. Seals made from this material were much better and did not wear as quickly any more. Oil was mixed with fuel and the engine ran! The engine was always hard starting and smoked like mad. It did, however, lead to a good working relationship with the Mazda rotary engine research division.



R100 Mazda Rotary with Autolite 600 cfm Four Valve Carburetor

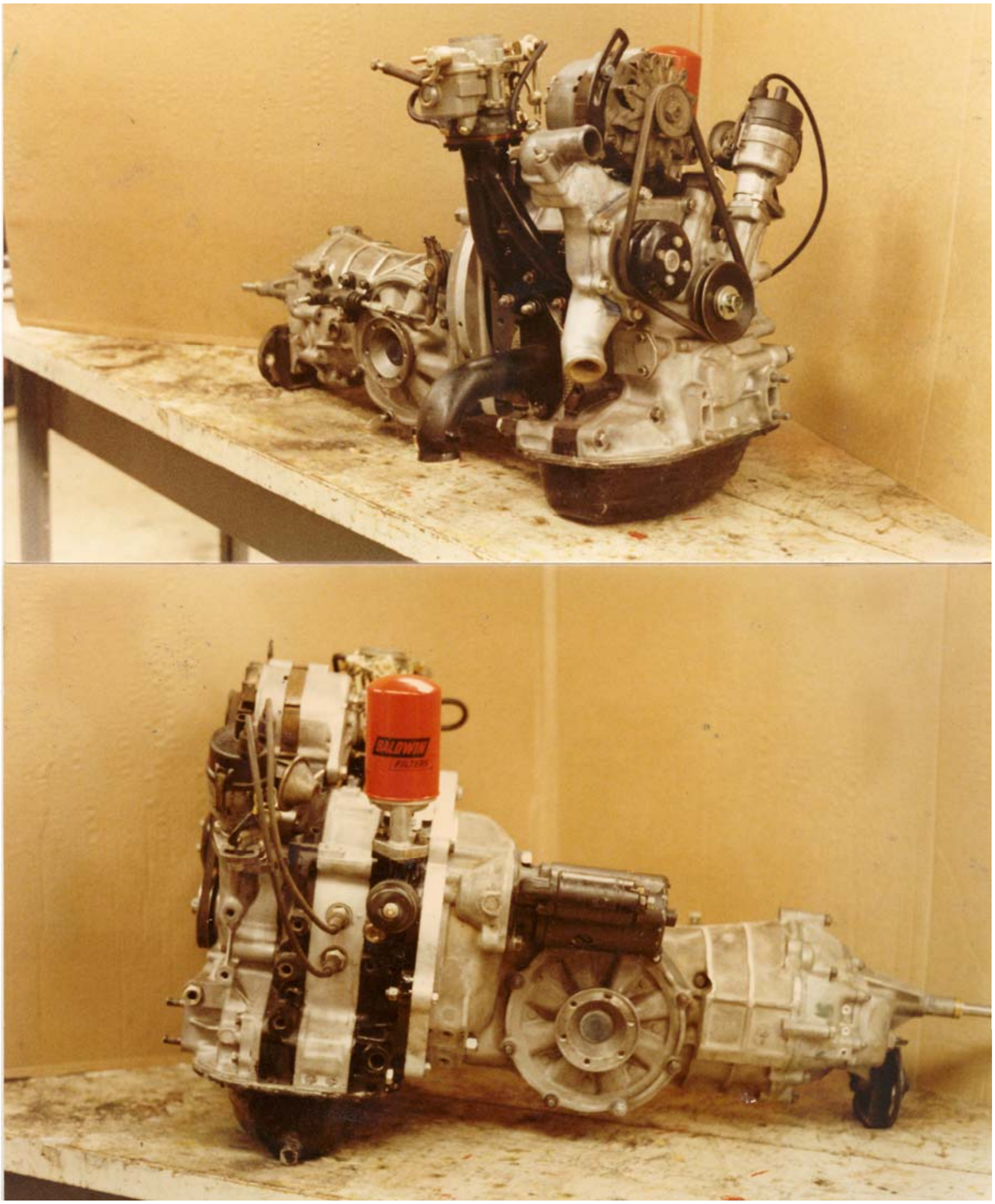
The first high performance engine utilized bridgeporting and a new intake manifold to fit an Autolite 600 cfm four barrel carburetor. In combination with a resonant ram tuned exhaust system, we were able to increase bmp from 90 to 245 bmp which provided a one-way run at the Bonneville Salt Flats at 186 mph. To provide suitable gearing in our modified Volkswagen Beetle transaxle, we developed an overdrive fifth gear made from another third gear and the synchro system mounted upside down in an overhung gear case. Thicker aluminum side plates for the differential housing were cast and machined to replace the thin magnesium ones. These cases were held together with 4130 steel through bolts as these transaxles suffer failed crown wheel and pinion gears under high torque conditions. Subsequent modifications to the Wankel rotary engine consisted of increasing the displacement from 1146 cc to 1308 cc and changing from side intake to machined peripheral ports and a 48 mm IDA Weber carburetor for a total bhp of 295 at 9600 rpm. The minimum useful rpm was 5500, and the engine was incredibly noisy.



Peripheral Port Wankel Rotary
Left to Right—Russ Moye, unknown, Bill Green

We built a stratified charge version using prechambers that screwed into the trailing spark plug hole. The prechambers have EFI with timed squirts that occurred 80 degrees before top dead center. Bill Brown machined apart early Bosch injectors and, thus, reduced the flow by limiting the lift. He then reassembled them by using a high temperature epoxy sleeve to replace the rolled over joint. The original four barrel carburetor was drastically “leaned out” to approximately 22:1 overall ratio. When we sent data to Hiroshima, the Mazda Company developed two similar versions of our design. Ultimately, stratified charge engines reached a dead end as they are intrinsically not as efficient as engines running at 10% leaner than stoichrometric and using catalytic converters.

In an effort to improve Wankel rotary engine fuel economy, we built a single rotor 500 cc engine using a Mazda engine rotor and epitrochoidal housing. Bill Brown machined an eccentric shaft for a single rotor design used in Viking IV, which achieved 50 mpg. Later, we made all the special components for a 654 cc single rotor engine for NASA Lewis Research Center in Cleveland. From the parts we supplied, the Research Center assembled a successful engine for aircraft use.



The Engine Designed for NASA Lewis Research Center

Race car builders using Mazda rotary engines began purchasing peripheral port housings from the VRI. For a short time these VRI ported housings were used in the top racing cars. This use continued until the Mazda factory began making these peripheral port housings available.

The Mini-Car Project

In 1974 The National Highway Safety Administration (NHTSA) contracted with Mini Cars, The Budd Company, Systems Technology Incorporated, Thiokol Corporation, RCA Laboratories, Monsanto Research Company, USM Corporation, University of Utah, Stanford Research Institute, and Man Factors Incorporated to design and build a number of research safety vehicles. They were to be lightweight, safe, energy-efficient cars which embodied state of the art engineering design and advanced concepts. When the cars were completed in 1979, the EPA under Joan Claybrook announced that these vehicles met the California emission standards for that year, and they would get 40 mpg. Unfortunately, neither seemed to be true, so NHTSA contracted with Dr. Seal to see that the vehicles met the emissions and fuel economy standards. Two of the cars were sent to the VRI. Later, Dr. Seal drove one of them to an emission laboratory in California so he could work on the emissions problem. He spent six weeks that summer working on the Honda Accord CVCC engine to achieve the desired emission standard. He succeeded in doing so a cost of eighty thousand dollars. Credit must also be given to Roger Rainey of Honda of America for his help with the Honda engine tuning for improved emission and mileage ratings.

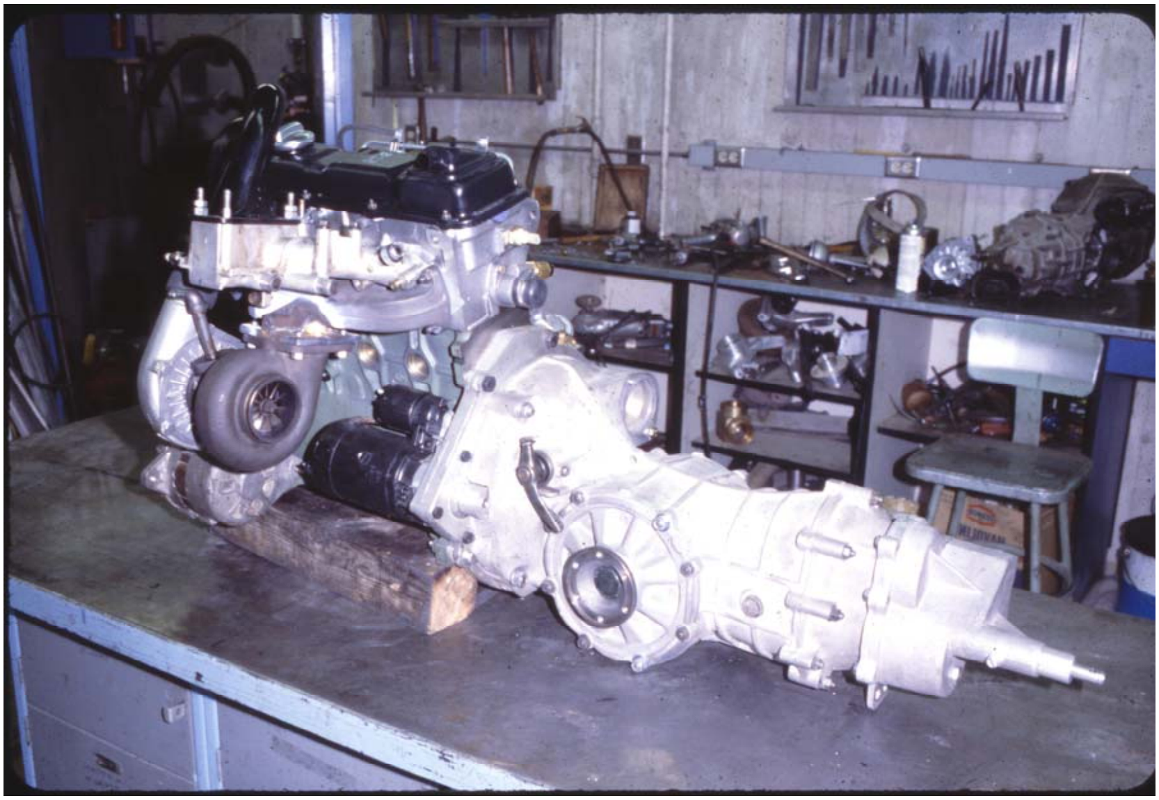
The NHTSA Sponsored Mini Car

Viking IV Air-Cooled Volkswagen Five Speed Transmission

An overdrive top gear was needed for Viking IV if it was to reach its target speed of 200 mph. We decided to fit an overdrive fifth gear to the Volkswagen gearbox. To do so, we took a page from our previous experience and mounted an extra housing on the back of a four speed gearbox and equipped it with a third gear, upside down, that we had pirated from another Volkswagen box. Two new shafts needed to be made to accommodate the extra gear, and a new shifter mechanism was devised. Bench testing showed that the gearbox shifted into all its gears, so it was fitted into Viking IV along with a Mazda Rx4 engine that we had modified for salt flats racing. On the first test the car accelerated smoothly through all five gears, and then we slowed and down-shifted from fifth to fourth gear. But when we tried to down-shift to third gear, it would not go into that gear. In fact, the only gear other than fifth it would go into was reverse. Strange to say, going into reverse freed up the other gears, and all gears were once more useful. After going through this cycle several times, we disassembled the transaxle and everything looked normal. Further investigation revealed that the reverse idler shaft had been made 1 mm too long. When the shift from fourth to fifth was made, the gear cluster struck the end of the too-long reverse gear idler and caused it to interlock the detents on the first and second gear shaft which prevented any axial movement of the dog clutches. Therefore, shifting into reverse reset the detents, so all gears became useful again. The solution was easy. Take the gear box apart and remove .040 mm from the end of the shaft.

The Turbo Diesel

An intake and exhaust manifold was made for a 1500 cc Volkswagen Dasher turbo diesel engine to adapt a B22 Rajay turbocharger to the engine. This engine was extremely successful in Viking IV. We were able to set a new record of 120 mph and were also able to exceed 100 mpg in the same configuration. Russ Moye drove the car from Bellingham to the Bonneville Salt Flats and back again. The next modification to this engine was to convert it to a pilot oil diesel configuration which was very efficient and virtually eliminated hydrocarbon emissions.



Turbo Dasher Diesel on the VRI made Five Speed Transaxle

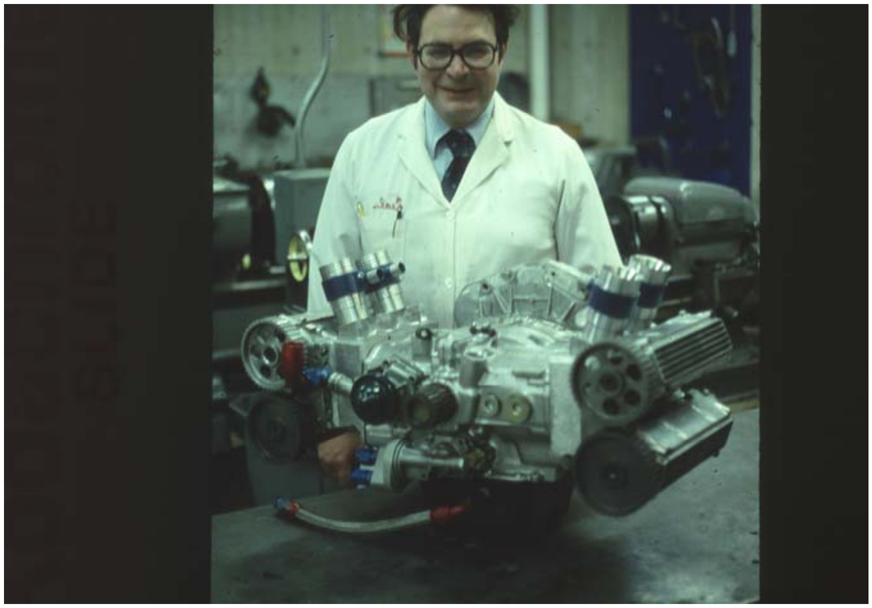
Viking V's Engines

Viking V was a fiberglass bodied clone of Viking IV, but it did feature some unique power plants. The first engine was not very successful. A 1600 cc Subaru Otto cycle engine was converted to run on diesel. To do this, we filled in the combustion chambers on stock Subaru heads with TIG welding. New ports and valve guides were machined into the heads, so they could be milled off flat. Comet MKV swirl chambers and Bosch distributor style injectors were fitted into the heads and small combustion pockets were milled into the piston crowns under the injector holes. As the engine has a 92 mm bore and a 60 mm stroke, the surface area to volume ratio was consequently very poor. The engine was hard starting and smoked a lot. As the first Sea to Sea Econorally was imminent, this engine was abandoned, and Viking V was fitted with a parallel twin Isuzu industrial engine that Bill Brown had just bought to run a gen-set on his boat. This engine was unusually rough but very economical. In fact, it vibrated the car so severely at idle that the central handle on the exit hatch would not open. As it was very difficult to stop the engine once it was running, it was difficult to get out of the vehicle. There was no way of shutting fuel delivery down, so an air flap blocking the intake passage was devised When attempting to shut down the engine, Bill would pull on a string that led over the roll bar to a box end wrench in the cockpit. This action would throttle the engine air. The governor would sense the engine slowing down and dump in more fuel to try and speed up the engine. Black smoke would appear in great clouds, and the driver would let out the clutch in fifth gear with his foot hard on the brake. These actions would eventually stop the engine.

After the VRI set a record using a Wankel Rotary engine, the Southern California Timing Association in charge of speed week at the Bonneville Salt Flats decreed that Wankel Rotary engines would be rated at three times their actual displacement. We decided to look at suitable two stroke engines because two strokes were given no displacement penalty compared to Otto cycle engines. The two liter Mercury V-6 outboard looked ideal. Kurt Willows, a very talented, hard-working student, and Dr. Seal negotiated with Lyle Forsgrin at Mercury Marine to acquire several suitable power heads. The crankshafts were modified so that a flywheel clutch could be fitted into the engines. A naturally aspirated power head and a turbocharged version were ported and fitted with resonant ram expansion chambers for each cylinder and electronic fuel injection. The naturally aspirated version always worked better than the turbo version. Viking V, which weighed under a 1,000 lbs., produced an enormous rooster tail and would go no faster than 150 mph because of severe traction limits.

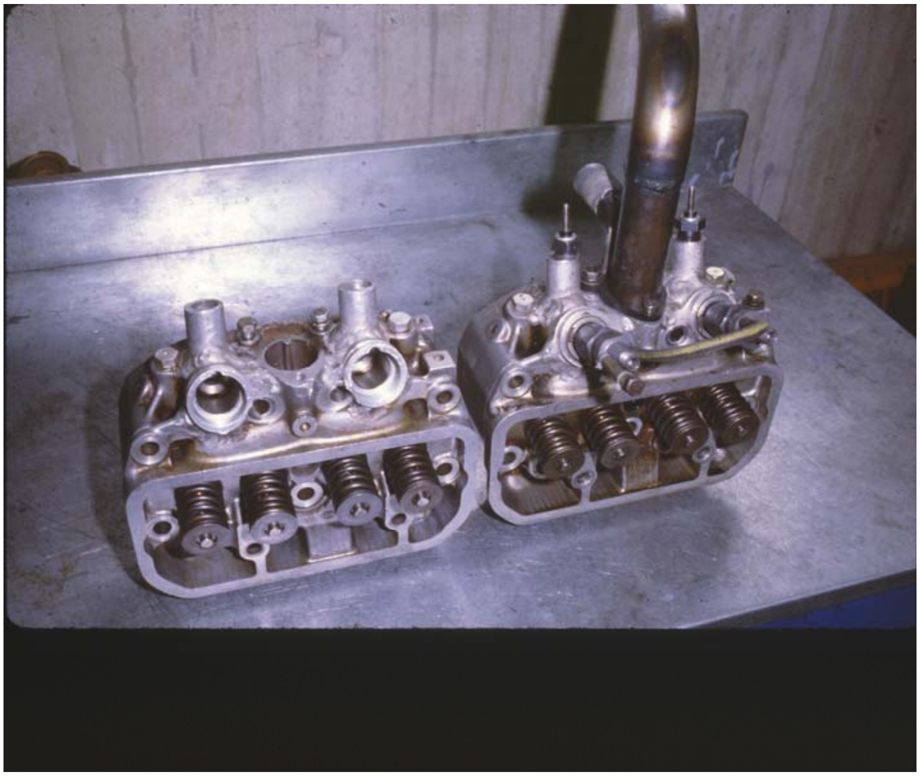
Subaru Engines Used by the VRI

The first prototype Subaru four-cam had a methane carburetor fitted to each intake tract and four equal length, individual exhaust pipes that joined at a collector just behind the engine. When we cranked the engine over for the first startup, the right bank began running but the left bank did not. In fact, exhaust smoke appeared to be backfiring out of the left bank carburetors. However, as the mixture strength increased, the engine began to smooth out and run on four cylinders, but the carburetors on the left bank were spitting out blue flames! The flames appeared because Dr. Seal had set up the camshafts on the right bank so that intake power and exhaust would occur at the right time on cylinder number one. He assumed that the left bank would be the same but ignored the fact that as all four camshafts turned clockwise the right bank would have its intake underneath through the exhaust valve and would, of course, exhaust out the intake. Since all of the engine exhausts converged on the collector, which was open to the air, the left bank pulled in air mixed with unburned fuel from the right bank, causing the engine to run rich but in an unusual fashion! The fix was quite easy: we merely retuned the two left side camshafts.



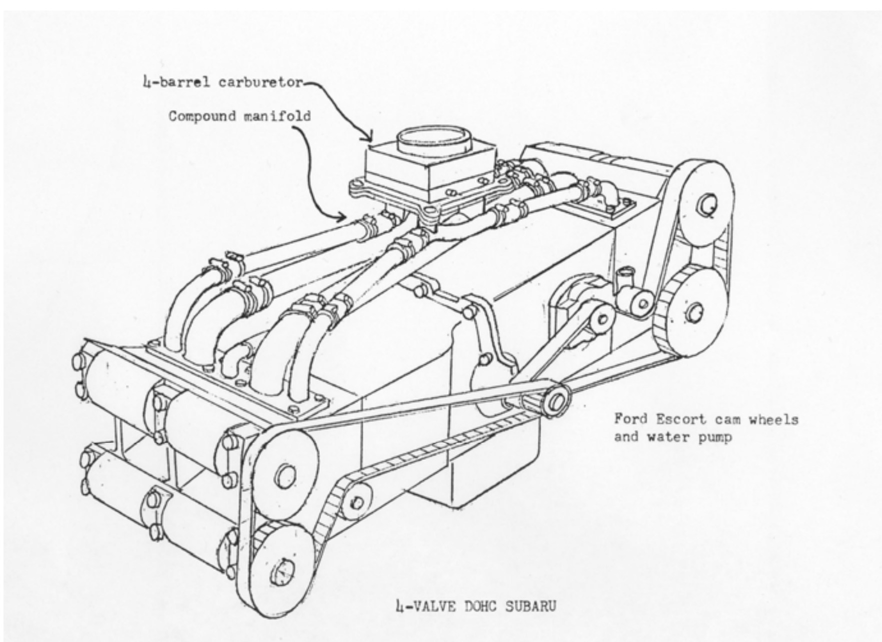
Michael Seal with the First Four Valve Subaru

The second Subaru 16 valve was developed under contract with the Subaru Company of Japan (Fuji Heavy Industries). The VRI developed patterns, core boxes, and cores so that we could cast the cylinder heads and cam boxes in the ET foundry. All machining was done in the VRI labs, using manual milling machines and lathes. Lotus cam shafts were cut in two to use in this engine, which obtained 133 bhp at 7000 rpm. After the engine was fitted with an oxidizing catalyst, it was able to meet the CA emission standards. This is the engine that was shipped to Japan and was reverse engineered for production and appeared as the first 4 valve engine sold in Japan. This engine was used as test bed for a short time in Viking 7. Although the engine was clean and fairly powerful at 135 bhp, Dr. Seal thought more performance would be desirable, so a SOHC 2 valve turbo experimental engine from FUJI Heavy Industries (Subaru's parent company) was fitted with increased boost to 12 psi above ambient. Although no dyno tests were run on this engine, 150 bhp and very good torque must have been available. The gearbox used in this configuration was a ten speed made from a combination of a five speed and a high/low splitter box from the four-wheel drive unit. While five speeds were barely enough for the four-cam engine, ten speeds were not necessary for the torque engine.



Jensen Healy Heads Before Cutting

The last versions of the Subaru 4 valve were sent to Japan, and Subaru reverse engineered the engine for a production run. The Subaru Legacy was fitted with a production 4 valve engine.



Original Drawing by Michael Seal of the 4 Valve Subaru Engine

Viking VI began with an 1100 cc Subaru engine left over from the Viking II project. Although economy was very good, power and torque were marginal for the expected performance. When a modern Subaru 1600 cc experimental engine was subsequently fitted, power, exhaust emissions, and fuel economy improved.

I remember . . .

The VRI Moves into the Computer Age

by Wes Williams

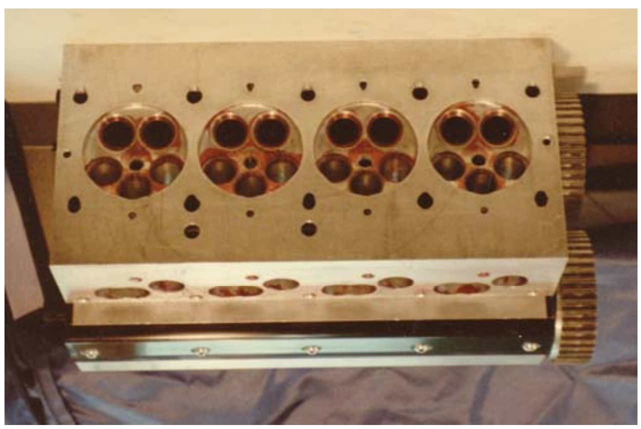
I spent 20 hours a day or more, for almost three straight years, between Professor Hill's and Professor Seal's labs. I was one of the few who helped move and set up both labs in the "new" technology building. I was involved in Vikings VII, VIII, and the F440. I was involved in both the Subaru and Chrysler head projects. I relentlessly hounded Professor Seal to get computers and CNC technology for the department, even stooping to the level of using the Plastics Lab's computers to solve design problems for the VRI because I knew doing so would irritate him no end. I helped in the pre-purchase evaluations of CAD/CAM systems and provided the initial ProE training for all that were interested. I also was privileged to spend many days sailing and enjoying family dinners with the Seals.

I remember when the VRI received a grant from Chrysler to do a 5 valve head design. Of course, the valve train was the key to the project, and its design was proving more than a challenge. I was a VERY strong CAD/CAM advocate, and I had lost a number of gentlemen's bets and side challenges to Professor Seal. Layout, sketches, renderings on the computer took days longer, looked worse, etc., etc., etc. . . . than his manual methods. But this project was different. Manual methods were not providing the solutions fast enough. The lead student (one of my best college friends) asked me to do some layouts on the computer. After a marathon AutoCAD session on the Plastics Lab's computer, I showed Professor Seal and my friend the computer designs. It was then I saw it: Professor Seal's eyes were different; his face also had a very different expression. It was the look of one who has resisted something for years, but finally knows he MUST change. The change was huge. Slowly, quietly, computers with CAD/CAM showed up in the VRI. Last time I was in the lab, there were still those marvelous white board sketches and renderings, along with advanced computer systems and machining centers that most any engineer or student could ever dream of laying hands on. But best of all, Professor Seal was a CAD Jock! Wonders never end in the VRI.

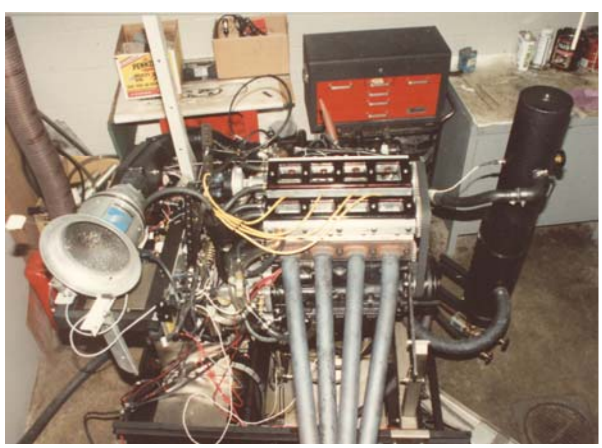
Professor Seal is one of a very small number of people whose philosophies, teachings, and lessons affected my daily life many years after graduation. As an engineer whose livelihood depends daily on all the core elements of a VRI education, I will be forever grateful for what I learned from his program and our friendship.

Five Valve Chrysler

In 1988 we won a contract with Chrysler to design and build a 5 valve cylinder version of the venerable 2.2 liter engine that powered almost everything Chrysler made in that era. Our design brief was to match the Turbo 2.2 liter engine for power and improve fuel economy without using a turbo. Dr. Seal did the initial design and drawing, and John McCoy volunteered his services to machine the head and attendant pieces out of aluminum billet stock. The three intake valve stems were parallel to each other with inverted bucket followers over each valve. A single camshaft with a very long lobe for the three valves drove BMW type finger followers between the camshaft and the staggered bucket followers. The exhaust cam bore directly on a pair of bucket followers per cylinder. An active resonant ram manifold was designed for the engine with progressive opening to first open one of the outside intake valve ports that were only connected to long runners, which were wrapped around the intake log to give resonant ram at 3600 rpm. Then, at 7000 rpm the short ram manifolds connected the other two ports to the plenum and swirl charged to tumble. Although our performance goals were met, Chrysler's accountants insisted that no one would buy a 5 valve engine, so Chrysler never claimed the engine. It still is on display in the VRI.



Chrysler 5 Valve Head



Chrysler 5 Valve Engine on Dyno

Chapter 12
Safety Again – Viking 32

Viking 32

Viking 32

Viking 32 is the last Viking car to be built under the direction of Dr. Seal. It was funded with $200,000 from WWU and an $800,000 contract from the Federal Highway Administration (FHWA). The Viking 32 hybrid safety vehicle attempts to show that a vehicle designed to produce little or no CO_2 can provide the desired features of a sport utility vehicle without giving up any of the desirable features of a passenger car. Unlike the hybrid vehicles currently sold in the USA which make minimal use of the electric drive, the Viking 32 has 100 hp (75 kW) available from the front drive electric propulsion motor and 100 hp (75 kW) from the rear drive internal combustion engine (ICE). Each system is used during the driving range in a manner that provides the highest efficiency possible unless maximum performance all wheel drive (AWD) is called for at wide open throttle (WOT) when both power plants run.

In city driving (less than 49 mph [74 kph]) the car drives on electric drive only until it reaches 80% depth of discharge on the battery. The hybrid computer takes a signal from the Amp-hour meter to trigger the ignition and start the motor, which cranks until engine oil pressure rises and signals a disconnect to the starting motor. The throttle linkage has a hydraulic cylinder inline that is normally collapsed, which prevents throttle movement of the ICE when in electric mode. Once started, the hydraulic cylinder fills with engine oil which causes the ICE throttle to catch up with the throttle pedal. This mechanism prevents jerks during the transition from electric drive to ICE propulsion. Once the ICE has started, the computer disconnects the drive signal to the linear potentiometer controlling the flow of power to the electric motor. The linear potentiometer on the brake pedal is always active, however, so that regenerative braking is available at all speeds even if the electric drive motor is not providing propulsion.

The comparatively light vehicle weight of 2200 lbs. (1000 Kg) and regenerative braking make vacuum boost unnecessary. As only 726 lbs. (330 Kg) is carried by the front wheels, power assisted steering is also unnecessary. Electric power steering was investigated, but about the only effect was increased weight on the front wheels. When full power to both axles is required, the throttle pedal is floored, and both systems drive the vehicle, which provides brilliant performance. During downhill driving whenever the brake pedal is lightly pressed, regeneration braking charges the propulsion battery, and the disc brakes' pads do not actually touch the disc. Speed above 50 mph (80 kph) triggers the switchover from electric drive to ICE only. When speed drops below 47.5 mph (75 kph) for more than 60 seconds, the ICE is shut down and electric drive resumes.

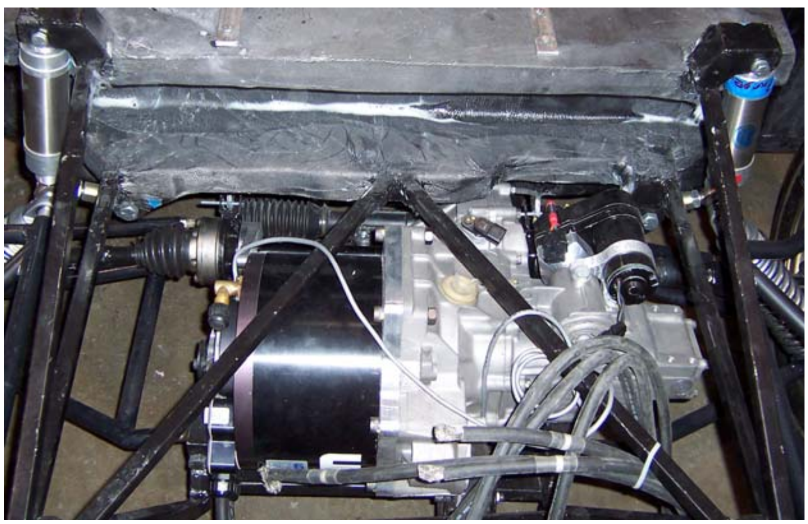
An idle stop strategy used by all existing commercially available hybrids is not needed because the normal low speed driving mode is electric only and stops, of course, when the vehicle stops. When the vehicle is below 30 mph (48 kph) in the high position in sport (S) mode on the shift lever, all propulsion systems run, and when the vehicle stops, the engine continues to run. Above 30 mph (48 kph) the vehicle drops to the lower ride height for greater stability. But the engine continues to run unless the shifter is moved to drive (D) where the engine stops until 50 mph (80 kph) for more than 60 seconds, and then it restarts.

The strategy outlined takes advantage of the excellent low speed torque curve of the electric drive for city driving and the greatly increased range at highway speeds. Daily driving to work or to get groceries should be possible entirely on electric power as the vehicle has a 27.5 mile (44 kilometer) range on the Nickel Metal Hydride battery. The vehicle is intended for plug-in charging at night as this is the cheapest form of energy. In the northwest part of the nation it is also the cleanest as nearly all of the power is derived from hydro generation. In the northeast, where the electrical power is derived from burning soft coal, it would probably be better not to plug the vehicle in at night.

Although we have not yet done so, the VRI plans to add a global positioning system (GPS) to the vehicle and incorporate vehicle location and direction into the hybrid strategy. As most American cities have only a few highways leading out of them to the next city, the learning program in the hybrid strategy computer would, over time, learn the likely duration of every freeway trip away from the home base city. An appropriate level of regeneration will then be set in regenerate braking so that the propulsion battery will be fully charged on reaching the next city. Then, all driving on surface streets in the destination city could be done with electric power.

As a hybrid vehicle there are two complete engine/transaxle and motor/ transaxle systems. The internal combustion engine used is a single overhead cam

(SOHC), 16 valve, 1668 cc, four-cylinder engine with a 75 mm bore and a 94.4 mm stroke with variable valve lift and duration. The engine has been configured to provide high swirl at low and medium speeds, thus giving fast burn when burning methane and eliminating the need for excessive spark advance on this high octane fuel. Coil on plug direct crankshaft triggered and electronic control unit (ECU) controlled ignition provided extremely good cold start ignition. Timed sequential fuel injection to each cylinder provides precise quantities of gas. The ECU has on-board diagnostic programmed into it which makes servicing possible. The relatively small bore (75 cm) and inherent volumetric efficiency limitations of gaseous fuel mean that the engine is limited to 100 hp (75 kW) at 5,800 rpm. The CVT makes good use of the generous torque to provide high performance and excellent fuel consumption. The vehicle can provide fuel consumption at 50 mpg (4.73 litres/100 Km) at freeway speeds and does even better in city driving. Using only this power plant the vehicle meets partial zero emission vehicle (PZEV) standards.



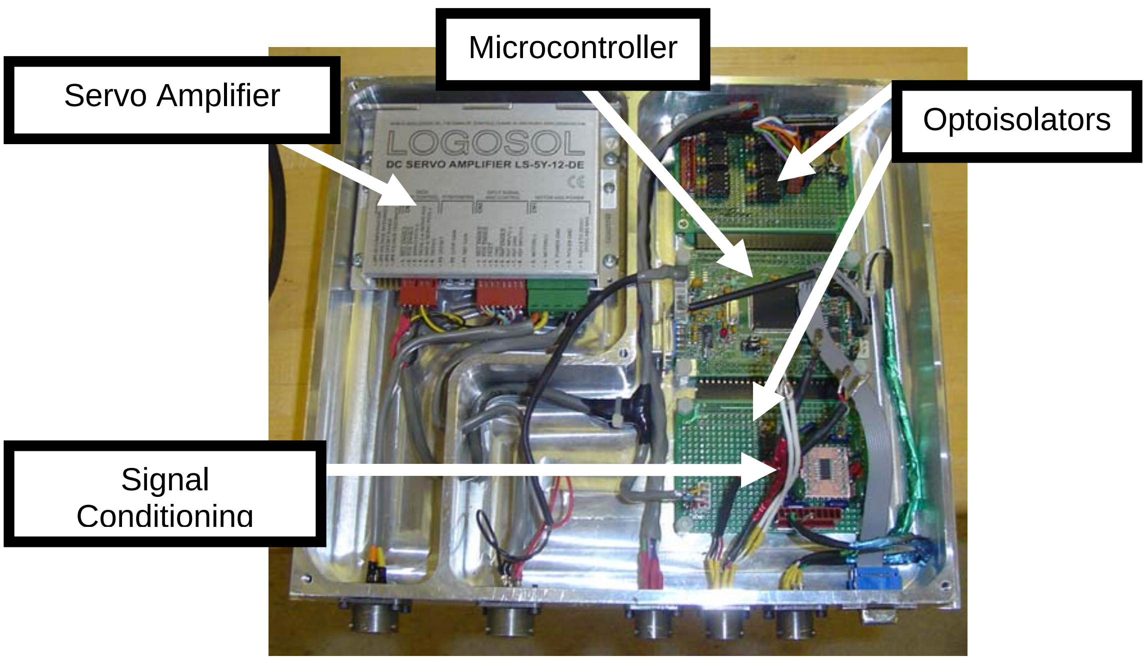
Electric Motor Transaxle

The automatic transmission used is a van Doorne type CVT, utilizing a steel belt running between two variable diameter variable width pulleys. The gear ratio varies from 2.466-0.449:1. The drive comes from the engine flywheel to the input planetary gearbox which gives forward and reverse gear by holding the sun gear and planet carrier respectively. Power is then transmitted through the CVT push belt to the output shaft that contains the multiple disc, oil pressure-operated starting clutch, which smoothly engages the pinion shaft for the final reduction of 4.357:1. This type of drive system provides efficiency and performance equal to a five speed manual transmission on the same engine in the same car.

Drive to the front wheels from the transversely mounted electric motor is through a two speed transaxle made from a Volkswagen Golf five speed unit. All gears and shafts save those needed for first and second gears are removed as is the unnecessary housing containing reverse gear. Substantial bulk and 22 lbs. (10 Kg) are saved in this manner, leaving 57.1 lbs. (25.5 Kg) weight for the front transaxle. As the motor weighs 127.6 lbs. (58 Kg) and the controller weighs 38.72

lbs. (17.6 Kg), the complete 100 bhp (75 kW) drive train weighs only 222lbs. (101 Kg). The two speed automatic shifter moves from the low ratio 12.661:1, which gives a speed of 47 mph (75 Km/hr) at 8,000 rpm, to the high ratio of 6.42:1, yielding a speed of 94 mph (151 Km/hr) at 8,000 rpm through use of a bespoke electric motor control system (EMACS)

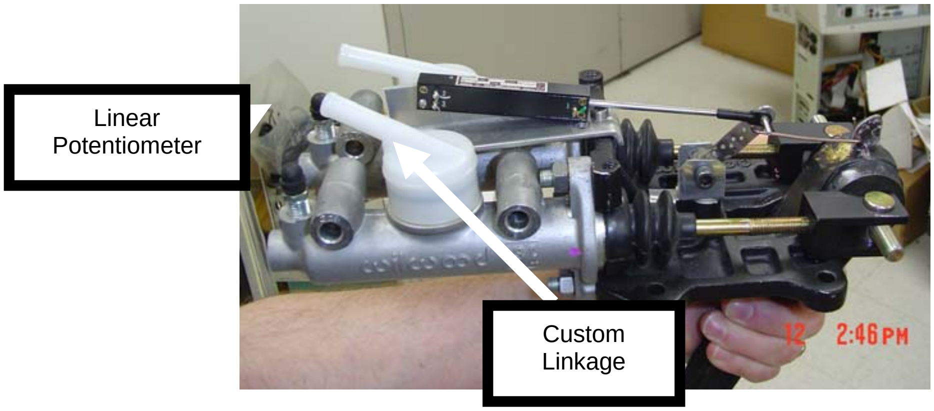
The EAMCS Control Unit was designed and constructed as pictured below. The enclosure was milled from a solid aluminum block. Two cavities were cut out: one cavity houses the micro controller, signal conditioning circuits, and optoisolators; the second cavity houses the shifter motor servo amplifier. The EAMCS Sensor Driver Unit provides the proper voltage and current required to ensure reliable, steady signals. The unit drives four different sensors in Viking 32: accelerator, brake, gear position, and the axle speed Hall Effect sensor. The unit shifts by matching input and output revolutions. For example, the vehicle speed signal (VSS) sends a signal to EMACS, which then pauses power delivery so the electric servo motor can withdraw the synchromesh selector collar from fist gear. A pulse is sent from the brake mounted potentiometer feed to slow the motor until the two Hall effect sensors detect near perfect matching.



EAMCS Control Unit

EAMCS Sensor Driver Unit

Instrumentation was accomplished by mounting linear potentiometers for both the accelerator and brake pedals. Each task was accomplished by constructing and modifying the pedal assemblies with custom in house built parts.



Brake Pedal Instrumentation

The 100 hp (75 kW), neodymium, permanent magnet, brushless, three-phase, D.C. motor is used to power the vehicles' front wheels. The motor controller uses a modified square wave variable, three-phase converter to provide lower noise and reduce low speed cogging effects. High power switching is handled with IGBT switching devices. Full regenerative braking is provided with control from a linear potentiometer mounted on the brake pedal. The throttle pedal also has a linear potentiometer fitted to the linkage to send a control signal to the electric motor control unit.

A 5 kW hr nickel medal hydrate (NiMH) battery is used in this car. The central tunnel has one unit containing forty-four 7.5 volt cells in series. This unit is in parallel with another forty-four series pack split into two units mounted under the rear seats. This 330 volt battery will propel the car 25 miles (40 Km) before the ICE starts.

Under the Seat Battery Pack

Selecting 4-wheel drive and high road clearance transforms the Viking 32 into a machine able to travel in snow as deep as 8 inches (203 mm). No interaxle differential or interaxle driveline is required because front drive is electric only, and the methane engine is the only drive to the rear axle.

The fuel tank serves a dual function as it is a carbon filament wound cylinder capable of holding 5840 lb/psi (400 bar) pressurized gas. This tank is strong enough to serve as a reaction member for the carbon fiber honeycomb crash energy management section at the rear of the vehicle. The primary regulator is mounted inside the axial spine of the tank where it drops pressure down to 145 lbs./psi (10 bar) where an external regulator drops it to 45/lbs./psi (3 bar), which is suitable for the gaseous fuel injection system. Fuel injection timed sequential injectors are triggered by the electronic control unit which uses a speed density strategy to control the pulse width at the injectors. Tail pipe oxygen sensors provide a feedback loop control of mixture strength. A crank triggered coil on plug high energy ignition system fires the high octane (130 octane) fuel at high compression ratio (12.5:1) to provide high efficiency. Use of EGR and a three-way catalyst with high platinum loading gives exceptionally low exhaust emissions.

Filament Wound Carbon Fiber CNG Tank

Exceptional low fuel consumption is made possible because the Viking 32 has very low rolling and aerodynamic drag and because the hybrid strategy only allows the engine to run when it is operating in its most efficient mode of high load and moderate speed. The 96% efficient electric drive is used for all low load situations. In fact, the engine doesn't idle after it has warmed up. The fuel consumption of 50 mpg (4.3 liters) gasoline equivalent/hundred kilometer means that total range achieved on the 80 liter tank filled to 3200 psi (220 bar) combined with the 5 kW hr nickel metal hydride battery gives a range of 437.5 miles (700 Km).

Front and rear bumpers in elastomeric foam core and flexible urethane skin are designed to withstand 5 mph parking damage. Carbon honeycomb material is used at each end to absorb enough energy to allow occupant survival in a 50 mph (80 kph) frontal crash and a 30 mph (48 kph) rear strike. An inverted wing between the front fenders and rear stub wings with end plates provide balanced aerodynamic down force for increased high speed stability with minimal effect on the driver's vision. The aerodynamic body shell is constructed of sandwich panel carbon fiber weighing only 165 lbs. (75 Kg). Although the windscreen is made from safety plate, the rest of windows are made from hard finished scratch resistant polycarbonate.

A large single door is mounted on each side of the vehicle to allow good access to front and rear seats. The doors are rear hinged to allow better driver and front seat passenger access when the car is parked near another vehicle or wall. Conventional SAE type crashworthy latches are used to hold the doors shut. Because the side windows are very large, a window within a window scheme, featuring a novel circular form, was utilized. A mini chain drive system allows either front or rear occupants to control the rotating side windows. Manual window cranks were used as it enabled a saving of 1.5 lbs. (700 gr.) per side over the lightest electric window lifts that could be found.

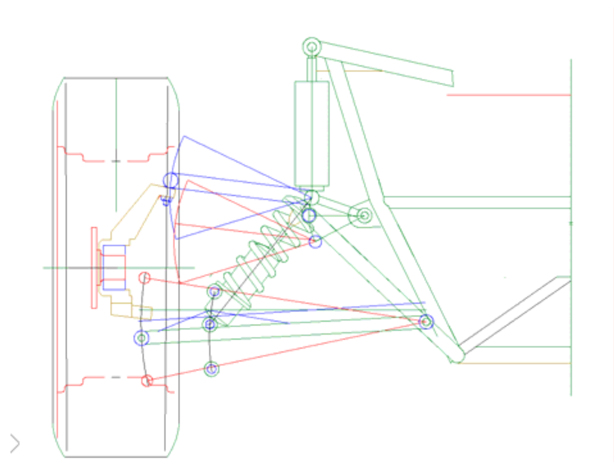
The body has fairly high frontal area by Viking car standards because upright seating was deemed to be desirable by an aging population. The aerodynamic shape is very good, however. Measured Cx in our wind tunnel is .33. This commendable number is achieved by using generous radii on the front of the vehicle and blending the “A” pillar with side window to provide good flow. The mirrors are on streamlined stalks mounted clear of the body so that flow behind them will not be disrupted along the body surface. The front wheel opening has small trip fences on the leading edge and generous radius on the trailing edge to reattach flow downstream from the wheel. The rear wheel openings have flush mounted covers to further lower aerodynamic drag. The bespoke outside door handles are completely flush with the body surface. To open the door, the rear of the elliptical handle is pushed in, which action pops the front of the handle out where it is easily pulled out to open the door. The underside of the car is completely flush to provide good under body airflow. A diffuser is fitted under the rear power unit. Radiator air is drawn in from the sides through NACA ducts beneath the doors. All windows are flush fit and all rain gutters are internal to reduce drag.

Viking 32

A normal heating, ventilation, and air conditioning system was essential in this car if it was to be accepted as a improved substitute for current SUVs. Fitting a conventional water heater run from waste combustion heat was relatively effortless. But even here the increased efficiency of the power trains causes less waste heat than that in most vehicles, and the generous-sized cabin has substantial internal volume. The use of foam-cored carbon fiber skinned aerodynamic body skin reduces conductive and convective heat loss through the skin. Use of polycarbonate for all glazing save for the laminated safely plate windscreen also helps reduce heat transmission. The floor, firewall, and toe board of the monocoque chassis tub are all made from 10 mm thick Nomex core honeycomb carbon fiber skinned material that is good for suppressing heat transmission.

Air conditioning is more difficult as the refrigeration pump needs substantial power to drive it. It was decided to belt drive the pump directly from the ICE and have no refrigerated air when the vehicle is in electric only mode. The HVAC unit is thermostatically controlled so that when the cab is too hot or too cold, the ICE will automatically start and continue to run until target temperature is reached. Under any circumstance, turning on the demister starts the engine so that air can be dried by refrigeration and then heated to make for rapid demisting. We examined the potential heat available from the electric motor and controller and determined that at 96% efficiency, insufficient heat was available to make recapture desirable.

In order to endow the Viking 32 with exemplary road holding in both high and low suspension setting and to avoid a system that would add much weight, we designed a long and short arm suspension geometry that is essentially the same at all four corners. Alignment of the rack and pinion steering with the lower wishbones eliminates bump steer.



Viking 32 Suspension

The power steering pump mounted on the engine is no longer needed for the steering so it is used to power the hydraulic lift system at 140 psi. A system of two- and three-way electric/hydraulic valves is used to direct flow to the cylinders at each suspension spring. Three inch (51 mm) diameter cylinders at the front and 3 inch (76 mm) diameter cylinders at the rear are used. In order to save weight, the system is designed to lock at the top and bottom of travel with no intermediate stops. In this way appropriate positioning of the lift link inner pivot point allows optimum camber at rest and appropriate camber gain in roll on the outside tires. Although low rolling drag tires are used to improve economy, aerodynamic down force from the wings more than compensate for loss in tire grip.

The chassis tub for the vehicle was designed using LSDyna and ProMechanica software to develop a stiff carbon fiber structure at a weight of only 121 lbs. (55 kg). The front chassis consists of a 45 lbs. (18 Kg) 4120 steel space frame ahead of a very stiff and well braced bulkhead. The chassis behind the rear seat bulkhead is also a 4120 steel space frame weighing 59.4 lbs. (27 Kg).

It has been determined that the lower half of the front toe board must slope backward so that the motor can swing under the car on short links to allow the front carbon fiber honeycomb structure to crush at the desired rate. This redesign from the original concept meant that very tight packaging for the air conditioning module became necessary. Because of the nature of the front monocoque structure, it became necessary to provide a removable sub frame under the front motor/transaxle unit to allow removal for servicing.

Low rolling drag high pressure P205 60 16 Michelin X tires provide substantially better low speed fuel economy. Large, extremely light, Al/Mg alloy wheels have low inertia and allow room for 12 inch (477 mm) ventilated disc brakes at all four corners of the vehicle. Honda calipers are used at the front while Ford SHO calipers are used at the rear to provide a serviceable hand brake capability.

The center passenger compartment is extremely stiff as it is constructed from carbon epoxy matrix composite. At each end carbon fiber honeycomb attenuators have been mounted. This structure provides occupant survivability in a frontal 50 mps (80 kpm) barrier crash and a 30 mph (48 kph) rear crash. At the rear, the carbon filament wrapped fuel tank provides the reaction member for the honeycomb material. The center cab structure has rollover protection moulded into the body structure. Airbags are mounded in the steering wheel and dashboard in front of the front seat passenger. Each front seat contains a side air bag which deploys in a side crash. The low center of gravity and camber gain suspension provide very quick maneuverability and resistance to overturn. Although the vehicle only weighs 2200 lbs. (1,000 Kg), it provides unusually high protection for its occupants.

Carbon Fiber Center Chassis

In May 2004, the Viking 32 competed in the sixteenth Tour de Sol five day competition sponsored by the Northeast Sustainable Energy Association (NESEA). This year the event started in Burlington, New Jersey, where technical inspection was completed, and fuel economy, acceleration, and braking tests were run over a three day period. The event then had an economy run to Trenton, New Jersey. After being on display in Trenton, the cars competed in an Autocross before moving on to the Seaport in New York City. They were displayed for the day, and in the late afternoon the awards were given out to the winners. Viking 32 won all the performance awards: best acceleration 0-74 mph in 6.2 seconds, best in braking, best time in the autocross. It achieved 50 mpg in fuel economy (our target for the contract). It was third overall in the light duty modified/prototype hybrid class.

Dr. Michael Seal was presented with the Northeast Sustainable Energy Association's George Bradford Teacher Award for encouraging his students to build environmentally friendly vehicles. After the competition Viking 32 was taken to be viewed by the contract officer at the Department of Transportation in Washington, D.C.

ACKNOWLEDGEMENTS

The editors want to thank the administration, faculty, and staff of Western Washington University, whose support of the VRI and cooperation with its projects over the years have been invaluable. We particularly thank former WWU President Paul Olscamp and the late Acting Provost Jim Albers, whose prompt action in 1975 officially established the fledgling vehicle design program as the Vehicle Research Institute. We also gratefully acknowledge the financial contributions of government agencies, private companies, and individual donors over many years. Without their assistance, the VRI could not have earned its reputation as “very possibly the best school in the country for total car design.”

We also thank the many contributors whose written accounts have so enriched this retrospective of the VRI and its director, Michael Seal. In addition, the editors most especially wish to thank the many VRI staff members and students whose research reports, press releases, and SAE papers made it possible to provide the technical details about the vehicles included in this book. For further information and details about specific vehicles or projects, please refer to their individual reports, listed in the following *Reference* pages. We call particular attention to the article of J. Burke, et al., in *Solar Cells.* This detailed description of the Viking XX solar race vehicle was written entirely by VRI students and won second place in the written design report competition accompanying the 1990 GM Sunrayce USA.

Most important, we want to acknowledge and thank the countless students who have provided thousands of hours of difficult and innovative work—testing designs, machining parts, assembling the vehicles, and driving them in competitions in England, Australia, and throughout the United States. With their unstinting enthusiasm, diligence, and discipline over the past 33 years, the VRI students have been instrumental in making the Vehicle Research Institute nationally recognized for its award-winning experimental vehicles.

References

Publications

Burke, J., Conrad, N., Dickerson, P., Jahns, S., Larson, D., Lingerfelter, W., Munn, E., Salmon, N., and Schmidt, G., "Viking XX—Western Washington University's Solar Race Car," *Solar Cells*, Vol. 31, No. 5, November 1991, pp. 443-458.

Cumberford, R., "The Craft of Design*," Alaska Airlines Magazine*, March 1990.

Dietrich, B., "A Driving Force in Cars' Future," *Seattle Times*, October 25, 1994.

Green, B., *Viking IV—An 87 mpg Sports Car*, SAE Technical Paper Series No. 810835, Society of Automotive Engineers, Warrendale, Pa., 1981.

Nadel, B., "Sun Racers," *Popular Science*, Vol. 237, No. 2, August 1990, pp. 49-53 and 88.

Richard, J., "A Fuelish Idea," *Sciences*, Volume 2, No. 5, June 1981.

Seal, M. R., Experimental *Urban Vehicle*, SAE Paper No. 730509, Society of Automotive Engineers, Warrendale, Pa., May 1973.

Seal, M. R., *How to Get 60 mpg.*, SAE Paper No. 800788, Society of Automotive Engineers, Warrendale, Pa., June 1980.

Seal, M. R., *High Performance Methane Engines,* SAE Paper No. 831074, Society of Automotive Engineers, Warrendale, Pa., 1981.

Seal, M. R., and Campbell, G., *The Ground-up Hybrid Vehicle Program at the Vehicle Research Institute,* SAE Paper No. SP-1105, Society of Automotive Engineers, Warrendale, Pa., August 1995.

Spitzer, R., "When Bellingham Talks, Lee Iacocca Listens," *Washington Magazine*, 1985, pp. 69-72.

Vickers, J. L., *Technical Features of the Viking V Research Vehicle*, SAE Paper No. 810938, Society of Automotive Engineers, Warrendale, Pa., August 1981.

Conference Papers and Unpublished Reports

.

Seal, M. R., “Viking VI—A Lightweight Two-Passenger Automobile Combining Improved Crashworthiness, Good Performance, and Excellent Fuel Economy,” The Ninth International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, November 1982.

Seal, M. R., and Fitzpatrick, M., “A Lightweight Two-Passenger Automobile Combining Improved Crashworthiness, Good Performance, And Excellent Fuel Economy,” Paris, France, November 1982.

Seal, M. R., West, E., Campbell, G., and Fraas, L.,“AThermophotovoltaic Generator For Use as An Auxiliary Power unit in a Hybrid Vehicle, International Symposium on Automotive Technology and Automation Conference, Italy, June 1996.

Seal, M. R., “Viking 21 Solar Electric Hybrid Vehicle, Final Report” (unpublished), August 1993.

Wood, J., Jackson, G., Seal, M. R., Zimmerman, G., Van Giffen, C., and Nelson, C., “Western Washington State College Urban Vehicle, Final Report” (unpublished), 1972.