A SURE FOUNDATION THE FOLLOW-UP ARTICLE

By David C. Seib

I met Martin Jansen, owner of Jule Enterprises, about 20 years ago. Back then I was curious about what he was offering as an aftermarket replacement, and since I lived in western NY it wasn't too far of a trip. The frame under my car was corroded and twisted, and I wanted to see the differences between this frame and the original. As background information, my B.S. degree is in Materials Science & Engineering, and at that point in my life I had just left working for an aircraft overhaul and repair facility in North Carolina. Mr. Jansen and I discussed the use of 0.125 inch thick steel tubing as the basis for the Jule Frame, and after that we parted ways except for an occasional phone call.

A few years later, Mr. Jansen asked if I could conduct a torsional test on the original Austin-Healey frame verses his Jule replacement frame. I traveled to Canada and showed him and a couple of his friends how to set up and run the test. Once the test was completed, I went home and performed the numerical analysis. The resulting article titled "A Sure Foundation" was published in the April 2000 edition of the Healey Marque magazine and compared the torsional strength of an original Austin-Healey 3000 frame to that of a Jule replacement frame. If you have not read that article, you should read it before continuing to read this one. But to paraphrase that article, it stated that the original Austin-Healey frame had a wall thickness of 0.072 inch, a torsional resistance of 635 ft-lb/degree, and a weight of 135 pounds. The Jule frame had a wall thickness of 0.125 inch, a torsional resistance of 1550 ft-lb/degree, and a weight of 215 pounds. The torsion tested original Austin-Healey frame and the aftermarket Jule frame were both verified to be in good condition, as degradation of either frame would have resulted in low torsional resistance values. My hope is that the earlier article was informative.

Fifteen years later there are still numerous questions regarding the Jule replacement chassis. Purists don't like it because it is not a faithful reproduction of the original. Mr. Jansen likes it because it is not as flimsy as the original and removes the scuttle shake issue.

I asked Martin Jansen why he didn't replicate the original frame in its entirety, with the single exception of using heavier gauge steel. His response was that he wanted his frames to be visibly different so that over time people would begin to see the difference in the two frames and prefer the one that was stronger. So it seems to me he chose this challenge to gain acceptance, knowing purists will always point out the variances from originality.
As a result, once a Jule frame is installed, the car is no longer capable of competing in a Concours competition. Alternatively, it is interesting to note that Jule Enterprises has been in business for 30 years. There is an acceptance regarding Jule framed cars among a group of owners who enjoy driving the cars.

Each of us, individually and collectively, as a Big Healey enthusiast ultimately decides the level of acceptance for Jule framed Austin-Healey cars and sets the market price for these cars accordingly. If considering a Jule frame, it is important to ask questions and determine for yourself the impact a Jule frame has on resale value and your personal goals. Also look at cars that have had original frames repaired or original style frame replacements and determine which cars are holding up better several years after restoration. Determine for yourself if sag is setting back in or are the lines crisp and straight. Frame-off restorations are expensive and getting the best value is important.

This article is a bit long, as I will try to address not only the condition of cars 50 – 60 years after original manufacture, but the knowledge and level of engineering that existed in the very early 1950s when the Healey 100 was first designed so as to put the topic in context.

AUTOMOTIVE SAFETY

Safety should be a first and foremost concern with any vehicle on the road, and as our cars age numerous components wear, corrode, crack, or need replacement.

Some Austin-Healey cars are beautifully restored from above, but underneath is where we all have to pay particular attention. Sadly, corrosion and degradation have taken a heavy toll on the frames and lower chassis surfaces of many of these cars over time. Corrosion protection when these cars were built consisted of paint, tar, or wax. The water splash and mud zones under the cars have undergone significant degradation over the years. Check for corrosion holes through the main frame rail lower and upper surfaces, outriggers, and sills. Look closely for shoddy main frame rail patch repairs, and buckling of the vertical portion of the main frame rails.

Open the bonnet and verify the fan belt can be easily replaced. It has been observed that as the frames under these cars deteriorate the radiator to pulley distance becomes so tight that the fan belt becomes nearly impossible to replace. Check door gaps and verify the doors open and close without hitting the bodywork. Door gap at the rear wing (i.e. fender) should be uniform from top to bottom, measuring approximately 3/16 inch.

In addition, be sure to check brakes and other mechanicals typical of any other older automobile. Inspect the expensive sheet metal skins for body filler and proper curvature on both the exterior and interior surfaces. Just remember that as these cars have increased in value over the years, so has the ingenuity of some people to present a lower quality car as something having higher financial worth.

A couple pages of historical information are needed before beginning the frame discussion.

"THE HEALEY STORY" BY GEOFFREY HEALEY

I suggest buying a book titled "The Healey Story" written by Donald Healey's son Geoffrey, who worked with his father in the design and development of what we now know as the Big Healey. The book is an enjoyable read for any Healey enthusiast and provides valuable bits of information concerning design, production issues, and race history.

The book discusses in brief the life and times of Donald Healey, who is referred to as DMH on most of the pages. DMH was a well know racer in the 1930s, who drove Triumphs, Rileys, and Invictas, and who ultimately progressed to Technical Director at Triumph. After WWII he started his own small automotive company using virtually all his assets, about £50,000, to get it started. There were a few investors as well. The average Englishman's annual salary at that time was about £200 per year.

DMH was essentially a chassis builder, and with each model he built the focus was on being able to achieve 100 mph or more. With each new model an engine was selected and a torsional test of the frame was performed to make sure it was adequate for 100 mph service. DMH was described as a man of detail, wanting to get it right, and driven by a vision.

Donald Healey's first production car was the Healey 2.4 liter Roadster and it began production in 1947. As stated by Geoffrey, the "frame design was such that the length of the side members was controlled by the maximum size that Westland Aeroparts company could fold on their machinery". The sales brochure stated, "Scientifically designed of immense strength, for light weight. Box section throughout. Straight side-members 6-inch deep". These cars were the fastest production cars in the world at that time and achieved 110 mph. Geoffrey also stated the chassis design was challenged in several areas; forward outrigger that tore from the chassis, cracks in the front suspension boxes, cracks where the X-member met the main frame rails, and cracks at the rear suspension Panhard rod attachment point. Modifications were undertaken to fix the chassis issues and retrofits were performed on all production cars already sold.

The Healey Silverstone was the next model produced by Donald Healey. Geoffrey stated that poor aerodynamics severely limited this 3.8 liter Nash powered car at speeds of 100 mph and caused the engine to work too hard on the race track and ultimately overheat.

The Nash-Healey was the next car to bear the Healey name. It would achieve a commendable race history during the very early 1950s. Page 40 of the book describes a torsional test used to evaluate torsional strength of the Nash-Healey box frame so that the chassis could handle the longer Nash engine. After assuring the new frames were as strong as the earlier Healey frames, production of frames was undertaken at the John Thompson Motor Pressings Company. A series of challenges and remedies typical of development are described on the next few pages, such as tires, brakes, aerodynamics, fuel, and other issues. Race successes were enjoyed by the early Nash-Healey models that used aluminum wings (i.e. fenders), rather than the later heavier cars using steel wings. A total of 506 Nash-Healey cars were built between December 1950 and August 1954, with engines produced by Nash, chassis manufactured by Healey, and body work installed by Pinin Farina of Italy. Cost of these cars was 10 - 15% less than a Ferrari, too high a price to sell many vehicles.

Geoffrey's book then describes DMH's desire in 1951 to build a 100 mph sport car for the American market, targeting the gap between the dated 80 mph MG TD and higher priced 120 mph Jaguar XK120. He also targeted a sell price under £1,000 to avoid the British luxury sales tax, which would have doubled the tax on the car. Donald and Geoffrey evaluated several mass production engines of the day and decided on the Austin Atlantic A90 four-cylinder for the job. Agreement for Donald Healey to be provided A90 engines was achieved with Len Lord of Austin on November 27, 1951.

BRITISH MOTOR COMPANY (BMC)

Austin manufactured the A90 Atlantic Saloon during 1949 – 1952 in an unsuccessful attempt to penetrate the American market. The bonnet (i.e. hood) was lowered to improve aerodynamics, and side draft SU carburetors had to be used rather than down drafts due to height restraints. It used a newly designed post war over-head valve 4 cylinder 2660 cc engine coupled to a column shift transmission. Austin took the A90 Atlantic to the Indianapolis 500 speedway and time trialed the car to demonstrate its capabilities. The car achieved an average speed for 7 days of 70.54 mph and broke numerous speed records within its classification. Americans took little interest in the car, but Donald Healey determined the engine had a nice power to weight ratio and was quite suitable for his new car, the Healey 100.

The Austin and Morris companies merged in early 1952. This brought together Austin, Morris, MG, Riley, and Wolseley as one company. The Austin A90 Atlantic was replaced by the Austin A90 Westminster in 1954. The Westminster used the new C-series 6 cylinder 2639 cc engine and 4 speed column shift transmission. This drivetrain was incorporated in the Austin-Healey 100-six in 1956, and then upgraded to a better performing larger bore 2912 cc version during 1959 that would power the Austin-Healey 3000.

"THE HEALEY STORY" BY GEOFFREY HEALEY, CONTINUED

In retrospect, it is easy to see the lessons of Donald Healey's past coming together as the Healey 100 was being developed. DMH was seeking to produce a high power to weight ratio, light weight, aerodynamic, aluminum winged, low cost vehicle, capable of 100 mph, with a reclining curved windscreen to reduce aerodynamic drag, from readily available low cost parts, and that would have appeal to American taste. I believe we can all agree that the timeless Big Healey was a success.

After securing a reliable source for low cost engines, the next step was frame design. Pages 40 & 48 of Geoffrey's book describes torsional stiffness testing, the same test re-created at Jule Enterprises years ago. Geoffrey Healey states "calculations of torsional rigidity and beam strength took a lot of time using seven-figure log tables." Floor pan and outrigger designs came from methods learned while Geoff was on a visit to Pinin Farina in Italy during production of the Nash-Healey.

John Thompson Motor Pressings produced the proto-type frames. Thompsons is stated as requesting the frame boxes be edge welded together top and bottom so as to use the new welding system they had introduced to Land Rover which would not distort the frames during welding. The first Big Healey frame was produced in six weeks. Door sag was an initial issue and the sill under the door was strengthened by adding an additional "U" section along the top of the sill. During early driving trials, scuttle shake introduced vibration into the steering column, and this was corrected by a lateral brace between the front door pillars. First speed tests were recorded at 106 mph. The car was completed and shown at the 1952 Earls Court International Motor Show. The car was a success and Len Lord the Chairman of Austin approached DMH to put it in production under the Austin nameplate. Austin was capable of building far more cars than Healey, and was the drivetrain manufacturer, so a deal was struck. Only the first 25 Austin-Healey 100 models were manufactured at the Healey factory, all subsequent Big Healey cars were produced in Austin / BMC factories.

The Healey Company was paid for the Healey 100 design, received a stipend for each car built, and most importantly to Donald Healy was provided money to race. Austin wanted race track success to promote the Austin Company in the USA.

AUTOMOTIVE ENGINEERING TIMELINE, CORROSION PROTECTION & METAL FATIGUE

The Healey 100 and 3000 is a product of its development era, the early 1950s. This was an era before many automotive improvements we take for granted today. Think of the tools, materials, and engineering skills of that day. Engineering analysis consisted of trigonometry, calculus, log tables, slide rulers, classical engineering formulas & tables, extrapolations using French curves, and good sense & experience. Instrumented tests used dial gauges and manual recording methods. Hand calculators and computer analysis were decades in the future. Metallurgical engineering was a new field, just begun during WW II. Cars still used DC electrics and had very few electric conveniences.

The Healey design was intended to be light weight for race applications, no consideration was given to useful service five or more decades after initial manufacture. Corrosion was commonplace in many cars after just a few years of service. Consider a recent conversation you had with a Healey owner who restored his or her car, were the frame, outrigger, and sill corrosion issues about the same as yours? Did the mud & water splash zones such as floorboards, footboards, rear inner wings, and boot floor look more like Swiss cheese than steel? These consistent areas that need to be addressed are a testament to the vulnerability of the original design to degradation by rust.

Corrosion protection in pre-1980s cars consisted of heaver steel and thicker paint. Donald Healey was producing a light weight racer, so heavier steel was not in the plan. The automotive industry didn't begin to incorporate today's corrosion standards until the late 1980s. Specifically, it wasn't until 1987 that the American, European, and Japanese automobile industries adopted a 10-year corrosion perforation and 5-year cosmetic warranty which in turn drove galvanized steel to become standard on new cars. (Galvanization is simply a uniform layer of zinc tightly adhered onto the steels surface. Since zinc is more chemically active with oxygen than steel, and the developed zinc oxide film is not porous, it protects the underlying surface from further oxygen penetration and provides considerable corrosion protection.)

Fatigue cracking and fracture in the early 1950s was considered the result of a repeated or cyclic stress sufficiently high to induce cracking, but low enough so as to not permanently deform the component. Today, the stress limit below which no fatigue cracks occur is considerably better defined and is called the fatigue endurance limit. Companies and government agencies such as NASA have spent decades and considerable money since the 1950s to better define the fatigue endurance limit for many materials, as well as types of loading cycles and conditions that accelerate fatigue cracking. Ongoing fatigue tests have helped engineers understand weld geometries that produce the best and worst fatigue results.

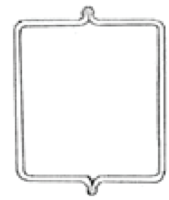
The development of many of today's fatigue data and stress analysis capabilities were initiated after three De Havilland Comet passenger jet disasters that occurred in 1953-1954. It is important to note those events occurred after design of the Big Healey was complete. Donald Healey, his son Geoffrey, and the vast majority of engineers in 1951 had only a limited understanding of fatigue cracking.

BIG HEALEY FRAME, SHAPE, AND THICKNESS

Austin Healey 100 and 3000 cars are built on an underslung box frame. Underslung is an old term meaning the frame passes under the rear axle. The frame consists of two main frame rails extending the length of the car, three cross-members, and an X-member. The location of the three cross-members is one at the front suspension attachment, one at the forward leaf spring attachment, and one at the rear leaf spring attachment. Each cross-member is strategically located to carry a suspension load across the width of the car, and support the weight of the body where it attaches to the outriggers. Both the forward and rear cross-members are easily recognizable, but the middle cross-member at the front leaf spring attachment may not be as recognizable. The middle cross-member is not a continuous tube extending between the two main frame rails, but appears as a pair of short tubes extending from the main frame rails to the X-member. The X-member therefore serves dual purposes; it is the forward leaf spring attachment cross-member, and provides torsional bracing for the main frame rails. As torsional bracing the X-member sets length-wise positioning of the two main frame rails relative to each other so that each main rail does not flex forward or rearward relative to the other main rail while the car is being driven, and provides torsional rigidity. Any structural engineer or builder will testify to the strength of a triangle, and the X-member forms triangular patterns with the main frame rails.

Mr. Healey chose to use 0.072 inch thick sheet metal stampings 10 feet long to produce the frame boxes. ***Because of this decision, this car frame is nothing like any American street car of the era, and after a half century of use requires investigation and a possible replacement decision.*** Each box consists of two sheet metal stampings having the cross-sectional shape of a "C". Two C-channels were fitted together to form a closed box and an edge weld was performed on the upper and lower surfaces. From what I have read these welds were performed using a new process known as "heli-arc", or what we know today as GTAW or TIG welding. The edge weld was selected by Thompsons because it produced far less distortion than other welding techniques. An original framed car can be identified by the approximately 1/8 inch tall by 1/8 inch wide weld bead produced by this weld process that extends lengthwise along the middle of the upper and lower main frame rail surfaces. Note that the weld bead is an essential ingredient of a Concours car restoration, so deciding that the existing frame still has useful life is essential if Concours is the goal.

CROSS-SECTION OF HEALEY TUBE FRAME WITH EDGE WELDS ON TOP AND BOTTOM.



One feature of the original main frame rails is that the top surface is flat, but that the bottom surface is a long curve with the greatest vertical height at the foot board position and decreased vertical height both forward and aft of the footboard position. Mathematically, the vertical height of the main frame rails is greatest where the longitudinal bending loads due to motor, transmission, and passenger weight are the greatest. Frame height is lessened at the front and rear of the car where longitudinal bending stresses are lower and additional ground clearance is needed. It is also important to note that these frames were painted on the outside, but not on the inside.

A quick summary of the frame is as follows;

- Carbon steel sheet, 0.072 inch thick, was formed into the shape of C-channels.
- Two C-channels were edge welded together to form a rectangular tube.
- Eight rectangular tubes were welded together to create the frame, excluding outriggers.
- The two main frame rails had flat upper surfaces, and curved lower surfaces.
- Numerous holes were cut into the frame for brake lines and other attachments.
- No corrosion protection was provided inside the frame tubes.

ENGINEERING BASICS

A car frame in motion experiences more loading than simple static bending, it is also subjected to dynamic torque. Mr. Healey knew this and performed torsional testing on each new frame design so as to confirm compatibility for expected road speeds. Torsional loads resulting from engine torque, maneuvering corners, braking, and poor road condition are required to be resisted by the torsional stiffness of the frame so as to maintain correct tire position and maintain steering ability.

In Strength of Materials classes, engineers learn that each structural member has a centroid. If a circle is drawn on paper, the centroid is in the center of the circle. Likewise, if a square is drawn, then the centroid is the center of the square. In terms of a car frame, the circle represents a round tube frame, and the square represents a box tube frame. When bending or torsion is applied to a tube, the centroid establishes a neutral point or plane. Maximum load is carried by metal surfaces furthest distance from the centroid and in-line with the applied load. A hollow tube is quite effective at resisting bending and torsional loads based on this principle. The thicker the metal surfaces and the greater the distance from the centroid, the greater the capacity of the metal tube to resist applied loads, provided wall thickness is sufficiently thick to avoid buckling.

A round tube provides the best resistance to torsional loads. Some cars actually use a cylindrical torque tube installed in the middle of the car along its length to provide maximum torsional resistance (such as a couple Lotus models). Instead of confronting the design complications of using round tubing, Mr. Healey chose a square or rectangular box. This is not as efficient in torsion as round tubing, but is still very effective, as a continuous circumferential hoop is formed. Interestingly, a square tube is more effective at supporting bending loads than a round tube, and lends itself to creating a flat surface for the installation of floor panels. The engineering compromise to use rectangular tube was quite reasonable.

As a side note, if the longitudinal edge weld of the frame is cracked or split then the continuous circumferential hoop is broken, and from an engineering perspective the torsional resistance of the tube is reduced to less than 1% of its original torsional resistance at that location. This important engineering consideration is why racing cars are designed using cylindrical or box tube as opposed to C-channel or I-Beam for frames. This can be easily verified by folding a long piece of paper into a 4 edged long tube, applying a little tape to both ends of the seam to hold end shape, and applying a modest torque. Now apply tape to the entire longitudinal seam and apply torque. There is a substantial difference!

An additional engineering concept to be maintained when using rectangular or box tubing is that when welding two pieces together, it is important to align flat surfaces to be on the same mathematical plane and weld corners to corners as much as possible.

Consider a Big Healey outrigger. The top surface is welded to the top surface of a main frame rail, and the bottom surface is welded to the bottom surface of a main frame rail. Stresses on the top and bottom surfaces of the outrigger transfer easily to the top and bottom surfaces of the main frame rails as these surfaces are on the same plane. The welds on the forward and aft faces of the outriggers are a different story, there is no continuation of these surfaces inside the hollow boxes of the main frame rails, thus stresses on the forward and aft surfaces of the outriggers can't transfer easily to another surface on the same plane, but must turn 90° at the weld joint. Tensile and compressive forces along these vertical forward and aft faces would continuously push, pull, and flex the vertical wall of the main frame rail and result in cracks, if not for the welds on the top and bottom surfaces being on the same plane as the horizontal main frame rail surfaces and dramatically limiting motion of this type from occurring.

Rear outriggers are cantilevered beams used to support the weight of the body, frame, and cargo. During driving, the leaf spring attachments also must carry the thrust loads from the tires, leaf spring torque, and about 1/3 of the braking load used to stop the car. To handle these longitudinal and torque loads, triangular braces are welded to the intersection of the outriggers and main frame rails. These 45° braces stiffen the rear outriggers, increase weld length along the top and bottom surface at the main frame rails, and decrease bending moment stresses on the welds.

Not all welds on a Big Healey frame comply with the above stated weld flat surface to flat surface principal, as I will demonstrate a bit later when discussing the motor mounts.

BIG HEALEY FRAME, TORSIONAL TEST IMPLICATION

It is hard to know 60 years later why 0.072 inch thick sheet steel was selected for the Big Healey box tube frame. The history of the Nash-Healey and Big Healey 100 / 3000 suggests power to weight ratio was given very high priority by Donald Healey, as increases in this ratio increases a car's race potential. We do know the finished product was tested in torsion by its designers and deemed acceptable by their criteria. We also know from our reproduction of the original test on an original Austin-Healey frame that when 635 ft-lb of torque is applied the original frame twists 1°.

To demonstrate the implication of the torsional test a crude mathematical exercise was performed to answer a typical automotive performance question. The question, what is the effect of lateral G force loading on a Healey frame as it manages a curve under full power? (Note, in engineering terms "1 G" is equivalent to the force of gravity.)

A Mazda Miata is listed as being capable of achieving a 0.8 G lateral force while cornering. Not being so aggressive, if we assume 0.33 G lateral force on a Big Healey while cornering, then we are assuming the combined 764 pound weight of the inline six cylinder Austin motor and four speed transmission is exerting 255 pounds of sideways (lateral) forces on the frame during a cornering maneuver. If the center of the frame is 1 foot below the center of gravity of the motor, the torque exerted on the frame during cornering at 0.33 G is 1 foot times 255 pounds plus potentially the full power engine output of 170 ft-lb, for a total of 425 ft-lb of torque on the frame. The torsional test of the original Healey frame performed at Jule Enterprises years ago was at an angle 25° from the longitudinal axis of the car. Translating the torque applied by the motor weight and power output to align with the torsional resistance test axis is accomplished by multiplying by cos (25°) and becomes 385 ft-lb. From just the motor and transmission lateral loads during this maneuver the frame is twisting 0.59 degrees between front and rear axles. Per the method of calculation used, the door striker pillar at about 3 feet from the center of the axis of rotation is twisted vertically sin(0.59°) x 36 inches = 0.37 inch. Under the same conditions, a Jule replacement frame would twist vertically at the same location 0.15 inch. This calculation doesn't include passenger, body shell, or cargo weight and their center of gravity heights above the frame, nor does it include the major forces exerted by the tires through the suspension connections into the frame. This calculation is therefore greatly simplified, but does provide some insight as to how much flexing can occur in an original Healey frame during driving on a curved flat surface at full power.

Take a look at the weld joining the rear superstructure to the forward outriggers located inside the rear axle cavity. Ever notice how many cars have fractured this weld? The rear superstructure is a very stiff box, with considerable bracing and resists flex during torsional loading of the frame. As the car frame twist and bends this weld is enduring tremendous loading. Ultimately, after repeated fatigue cycles this weld fractures. After this weld fractures some loss of stiffness occurs at the rear of the vehicle.

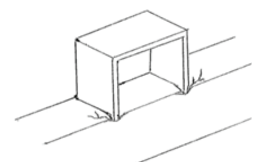
BIG HEALEY FRAME, ORIGINAL DESIGN WEAK POINTS

Effects of frame corrosion and cracking are detectable by door gap being very tight or non-existent at the top of the door where it meets the rear wing (i.e. "fender" or "quarter panel"), or after opening the bonnet the engine fan belt pulley is so close to the radiator that changing the belt may be impossible. These are symptoms of main frame sag.

Starting at the front of the car and working to the rear there are several different frame issues to be aware that occur.

Front cross-member between the front suspension is a common place where many people have lifted the cars up to get the front suspension off the ground. Splitting of the lower edge weld and crushing of the lower cross-member surface are characteristics of this type of lifting. If considerable crushing has occurred then tire alignment could be an issue. Do not lift the car using the front cross-member.

As a side note, having worked as a welding engineer, I have yet to come across a welding code that allows the weld to be weaker than the base metal or Heat Affected Zone (HAZ) on either side of the weld. Failure of a weld during weld testing means failure of the welding process used. Every edge weld crack I have seen in a Healey frame occurs through the middle of the weld, not the base metal or HAZ. For this reason, I am not impressed with these edge welds and suspect the weld size is too small.



Motor mounts tend to collapse into the frame at the outboard corners due to weight and dynamic vibration. Check the main frame rails at these welds and determine if cracks exist and extend along the top of the frame rails. This examination may involve a flashlight and removal of crud from the top main frame rail surfaces. If these cracks extend long enough to have seriously affected main frame rail strength, the top surface of the main frame rail will exhibit visible buckling and possibly twist. The primary cause of these cracks is the motor mount being an open three sided box not welded to both vertical surfaces of the main frame rails. Only the inboard side of the motor mounts is welded to a vertical main frame rail surface. At the outboard (open) side of the motor mounts, the vertical member of the main frame rail meets the vertical members of the motor mount at essentially two points. These points are highly loaded, supporting a load that should be spread out along a length of the upper outboard corner of each main frame rail. These point loads are like spears being driven into the main frame rails, and with the application of cyclic loading the result is the fatigue cracks observed.

An important maintenance item that can reduce the likelihood of the onset of motor mount fatigue cracking is to make sure the cable under the frame extending from the front of the X-member to the transmission is at proper tension. This cable prevents the engine from rolling forward during hard braking and excessively loading the motor mounts.

Front suspension lower A-arm rear linkage has a tendency to displace the frame attachment bracket toward the center-line of the car. If this has occurred, localized permanent frame twist will be evident. The cause is likely a combination of weak frame, braking loads, and / or high instantaneous loads associated with hitting pot holes.

Sheet metal box surrounding the brake and clutch master cylinders if distorted suggests the car was previously in a front end collision or the frame is so weak that it is sagging along the length of the car.

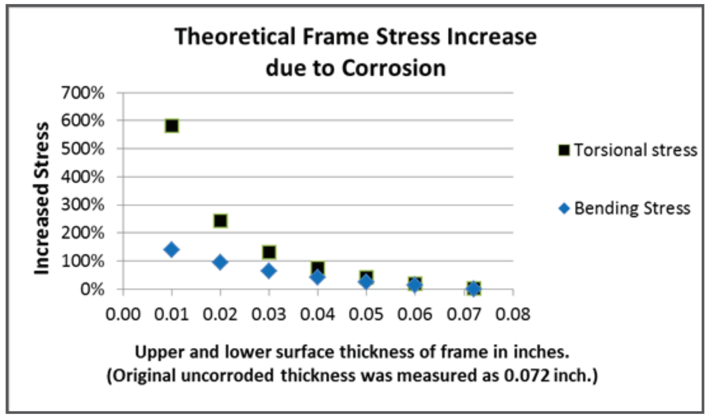
Shock tower bolts used to hold the front shock absorber in place are notorious for being threaded into stripped or non-existing nuts. Try to twist all four shock bolts by hand and verify that at a minimum the bolts are not just sitting in their holes for decoration.

Main frame rails are critical to the safety and function of the Austin-Healey 100 and 3000, as is true of all ladder framed open top cars of the 1950s era. The critical function of these main frame rails is especially important along the distance from the shock tower mounts to the most forward welds of the X-member. Along this length these two main frame rails are the only significant structure supporting the loads extending lengthwise from the front to the rear of the car.

Interior surfaces of the frame tubes were produced with no corrosion protection and as such are vulnerable to corrosion. It is important to realize that during original manufacture of the car that holes were drilled or tapped through the frame to attach brake lines, fuel lines, electrical wiring, and carpeting. Each of these holes actually created a weeping point for the entrance of water. As mentioned earlier, the frame is vertically deepest at the foot board, thus the bottom interior surface of each main frame rail forms a bowl. As water weeps into the frame it will flow to the nearest low point, which is the shape formed by the edge weld. As more water enters the frame it will flow to the bottom of the frame at the foot well location. Water repeatedly dwells at this same low point with each entrance and causes corrosion to be quite severe at this critical high stress location. Corrosion thinning of the 0.072 inch thick sheet metal occurs until structural integrity is an issue. Standing water on the top of the frame under the carpet or transmission tunnel causes rust at that upper surface location as well. The two vertical walls of the frame usually do not severely corrode, except at the outriggers where water in the outriggers lays against the frame.

It is also important to recognize salt water is much more corrosive than rain or fresh water. Anyone who has spent some time in close proximity to an Ocean, or in the northern part of the USA where salt is used to melt road ice, are well aware of salts negative effects on automobile sheet metal. Wherever corrosion is discussed in this paper, consider that the addition of salt will strongly accelerate metal loss by corrosion.

Corrosion of the upper and lower main frame rail surfaces causes increased stress on the remaining metal. Text book calculation of increased stress due to an equal amount of thinning of the upper and lower main frame rail surfaces was performed. Realize that a simple calculation of this type is limited in its capability, and is presented only as an example to better understand the effects of frame degradation. This calculation is not intended to imply a degree of deterioration that is safe. Each owner has to assess their own car by their own standards. The calculated points do indicate that torsional stress rises faster than longitudinal bending stress as a result of upper and lower frame surface thinning. The amount of stress increase starts slowly and as metal removal increases the stresses rise rapidly. Realize that at a 100% increase in stress the remaining metal of the main frame rails is handling twice the stress of the original Healey design. Mr. Healey's originally calculated safety margins for longitudinal torsion and bending stress are unknown.



After 60 years, depending upon how and where the car was kept, corrosion on the interior and exterior surfaces of the box frame can degrade the car to a dangerous condition. Cars have buckled and fractured in half at the foot well due to excessive corrosion of these main frame rails. ***Checking the vertical surfaces of both main frame rails for buckling and the top and bottom surfaces for open corrosion holes is very important.*** It only takes one of the two main frame rails being heavily corroded to make the car unsafe. Multilayer patchwork over corrosion holes masks the issue, and the fact these patches are present suggest danger is lurking underneath. I talked to one highly distraught father 20 years ago whose son was severely injured because of a main frame rail failure. Avoid the risks associated with ***a questionable Big Healey with doors that are difficult to close, an engine pulley almost touching the radiator, or a frame with corrosion holes or patchwork repairs.***

If the car was recently restored, recognize that cleaver frame patches and bondo may hide significant main frame rail issues. Check the main frame rail from the X-member to the front cross member thoroughly.

Some individuals believe inserting a tube into or on the main frame rails will strengthen or correct the problems associated with the onset of buckling. The problems with this approach are that the inserted tube is smaller diameter and because of this geometry very likely lower torsional and bending strength than the original frame, and then there is the question of where and how to attach this inserted tube to the original frame. To be effective the tube would have to be attached continuously along the length of frame from forward shock tower to at least the rear outrigger, and wherever this tube is attached reinforcement to the frame will have to occur to manage and transfer stress. The original damage and dimensional issues are still present in the original frame, and the tube is likely being welded to rust or thinned surfaces which are far from ideal. This type of "repair" is not recommended and could prove dangerous.

The same structural safety concerns apply when an L-channel is welded to or inside the frame. This is a patch intended to stretch frame life and usually does so poorly. An L-channel has nowhere near the torsional rigidity of a box or round tube and only provides the illusion of a benefit.

Forward outriggers, particularly the one over the exhaust pipes, are prone to corrosion. Consider how much faster the exhaust pipe side of the car rots from underneath compared to the other side, especially where the exhaust pipes are nearest the engine and at their hottest. Steam generated as water boils off hot exhaust pipes condense on cooler automobile underside surfaces. If exhaust leaks are present, carbon dioxide in the exhaust vapors combine with steam to form carbonic acid which is corrosive to steel. There is also a moisture sponge called a heat shield between the floor pan and the exhaust system. Heating of the heat shield releases moisture.

Because of the shape of an outrigger, any perforation in the outrigger that allows moisture to get inside at a location inboard of the exhaust pipes will allow water to flow downhill and rest against the main frame rail. Eventually this water will either rust through the bottom of the outrigger or the vertical wall of the main frame rail. If the water enters the main frame rail, it will add to the corrosion process at the bottom of main frame rail near the foot wells. From the earlier discussion, it is noted this location also happens to be the highest stressed region of the main frame rails. Slowing or stopping main frame rail corrosion at this location is a tough challenge. During restoration of a car, one possible solution is to weld a steel barrier 360 degrees around inside the outrigger about 1 inch from the main frame attachment, and then pour zinc chromate primer followed by paint into the outboard end of the outrigger and try to coat the steel barrier. Then weld the outrigger into position. The goal is to prevent water from reaching the main frame rail as much as possible.

Inner and outer sills are 18 gauge, or about 0.048 inch thick. Mathematically the torsional resistance of a welded sill is less than 15% of that of a main frame rail. Sills were never intended to add much torsional strength along the length of the car, but are critically important to prevent door sag. Geoffrey Healey actually added an upper bend to the inner sill to increase strength and minimize door sag during the original design phase of the car. Increasing sill thickness, particularly inner sill thickness, is beneficial during any refurbishment as it reduces the likelihood of door sag and increases the barrier thickness corrosion has to penetrate prior to entering the outriggers.

Stubby cross-members welded to the X-member at the rear outrigger have a tendency to bulge or swell. This behavior is not well understood, but the most likely mechanism would be compression, suggesting the distance between the X-member and main frame rails has decreased. Splitting of the edge welds of these stubby cross-members has also been observed.

Emergency hand brake welds to the box frame have exhibited fatigue cracking and fracture, leaving a ripped open hole in the top of the X-member. These welds should be inspected during any restoration.

Door pillar and door striker bottoms are prone to corrosion due to the overlapping sheet metal configuration. Remember in science class taking two plates of glass and putting water or oil along the edge and watching the fluid feed in-between the two plates? The mechanism pulling the liquid in-between the two plates is known as "capillary attraction". Corrosion engineers learn that that water or acid trapped in a cavity can behave up to 2 pH numbers more acidic than on a flat air exposed surface, essentially becoming 100 times more corrosive since pH readings are log base 10 values. Rain water is slightly acidic with a pH of 5 to 6.5. Rain water between two steel sheets can behave like vinegar or orange juice, having a pH of 3. The lower 4 inches of an Austin-Healey has numerous capillary attraction sites; sills, rockers, door pillars, floor panels, rear inner wings, and boot panels.

Under the rear axle the frame tends to get compressively bent. The jounce bumper is a thin pad of rubber between the frame and the axle. Its job is to soften the blow from the axle against the frame if the axle exceeds its normal travel range. Many cars have a compressed or buckled frame where the axle has induced a hard impact. This could be because the rear shock wasn't working properly or the rubber on the jounce bumper fell off, but either way a bent frame tends to rotate the rear body shell slightly upward at the rear and close door gap.

Rear shock mounting plate is vulnerable to fatigue cracks in the box frame around the weld at the lower forward corner of the shock plate.

Open floor under the gas tank is another place where moisture collects. This area is difficult to seal and lets water up into the boot while driving on rainy days. These cars simply weren't built to withstand the effects of water and sheet metal corrosion over time.

Rust is such an enemy to these cars it deserves a few parting comments. Rust can exist as a red flakey scale, Fe_2O_3, or as an oxygen starved tenacious black scale, Fe_3O_4. Both types of rust need to be removed. There are

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numerous products on the market that tout the ability to stop rust, but as yet I have no independent data to judge these products effectiveness. At this time, I still believe the best option is complete removal of rust to white metal and then zinc chromate primer followed by Urethane paint.

TODAY'S AFTERMARKET

Some aftermarket frames are now available in 2 mm (0.079 inch) thick sheet metal. As stated in the earlier article, AISC considers 3 inch square tubing having a wall thickness less than 0.085 inch to be susceptible to buckling. Mathematical calculations indicate the bending strength and torsional resistance of these 2 mm thick frames are increased about 9%, but the possibility that buckling could occur prematurely before this 9% gain is achieved is an open question. It is also worth noting that 2 mm (0.079 inch) wall thickness box tube frames are closer in design to the original frame and more likely to have characteristics closer to the original Austin-Healey frame (wall thickness 0.072 inch) than the aftermarket Jule Enterprises frame (wall thickness 0.125 inch).

Adding a 2 mm thick vertical member inside the box frame is another enhancement offered. Math suggests this vertical member enhances longitudinal bending strength an additional 18%, but because this vertical member is directly in-line with the centroid of the box it mathematically adds only about 0.02% torsional resistance.

Frame grafting by removing a section of frame and replacing it with another piece of frame has been performed on Austin-Healey cars. This type of open root weld repair requires a very skilled X-ray quality welder and perfectly mated parts. Considering the frame wall is only 0.072 inch thick, exact alignment is crucial. Misalignment leads to mismatched surfaces. If a mismatched surface is ground flush to achieve aesthetic purposes prior to paint, and the amount of metal removed is 0.020 inch, the frame's stress capability is reduced by 28%. This is why working with thin walled box frames can be so tricky and why frame grafting can be so dangerous. Recognize that frame grafting is prohibited in Canada due to the resulting number of deaths and injuries over a wide variety of automobiles.

INCREASED HORSEPOWER VEHICLES

Individual customization and after-market products have focused for years on providing increased horsepower options. It is essential when considering a horsepower increase that the frame can handle the torque. Never use a deteriorated frame and increased horsepower on the same car.

CONCLUSION

Restoring a Big Healey can be an expensive undertaking. Rust is not limited to cosmetic items such as wings (fender skirts), doors, and rocker panels. It is important to work with a shop that understands box frame construction and the corrosion issues associated with this type of frame. Most importantly make sure the frame is structurally sound (original or aftermarket) before proceeding with any restoration.

As these cars are typically not daily drivers anymore, each owner needs to consider his or her goals before deciding the correct restoration path. Ask for who is the car being restored and why, and what are the costs and rewards? There is a belief that originality increases the value of any car, but this isn't necessarily true when it comes to an Austin-Healey frame. Watch resale prices of factory and non-original framed cars and determine what is true if this is a concern.

DISCLAIMER:

The above article is meant for educational purposes only, to provide Austin-Healey 100 and 3000 owners a better understanding of the structure under the vehicles. Calculations in the article are based on simple engineering school mathematical formulas. There are no implied warranties in this article, and the presented results include no safety factors. Each owner is responsible to determine their own safety risks based on his or her experience, or hire appropriate skilled personnel to assess their specific individual frame condition and determine risks.

My hope is this article clarified some of the structural issues associated with the Austin-Healey automobile, and helps owners make better informed decisions on how to best extend the life of these beautiful cars.

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Thank you to Mr. Martin Jansen for input concerning common trouble spots found in Austin-Healey 100 and 3000 vehicles prior to restoration.