



## **Repair of Corrosion in Air Supply Piping at the NASA Glenn Research Center's 1 by 1 Foot Supersonic Wind Tunnel**

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## 1.0 Summary

During a test at the NASA Glenn Research Center's 1X1 Supersonic Wing Tunnel, it was discovered that particles entrained in the air flow were damaging the pressure sensitive paint on a test article. An investigation found the source of the entrained particles to be rust on the internal surfaces of the air supply piping. To remedy the situation, the air supply line components made from carbon steel were either refurbished or replaced with new stainless steel components. The refurbishment process included various combinations of chemical cleaning, bead blasting, painting and plating.

## 2.0 1X1 SWT Facility Overview

The 1X1 Supersonic Wind Tunnel was originally built around 1949. Many improvements have been made over the years. Recently, in 1989, an additional piping circuit with an electric heater was installed allowing the tunnel's speed range to be extended to Mach 6. Like all of the original air piping systems, the heater circuit was installed using carbon steel components.

Figure 2.1 provides an isometric cut-away view of the 1X1 SWT. Compressed air is

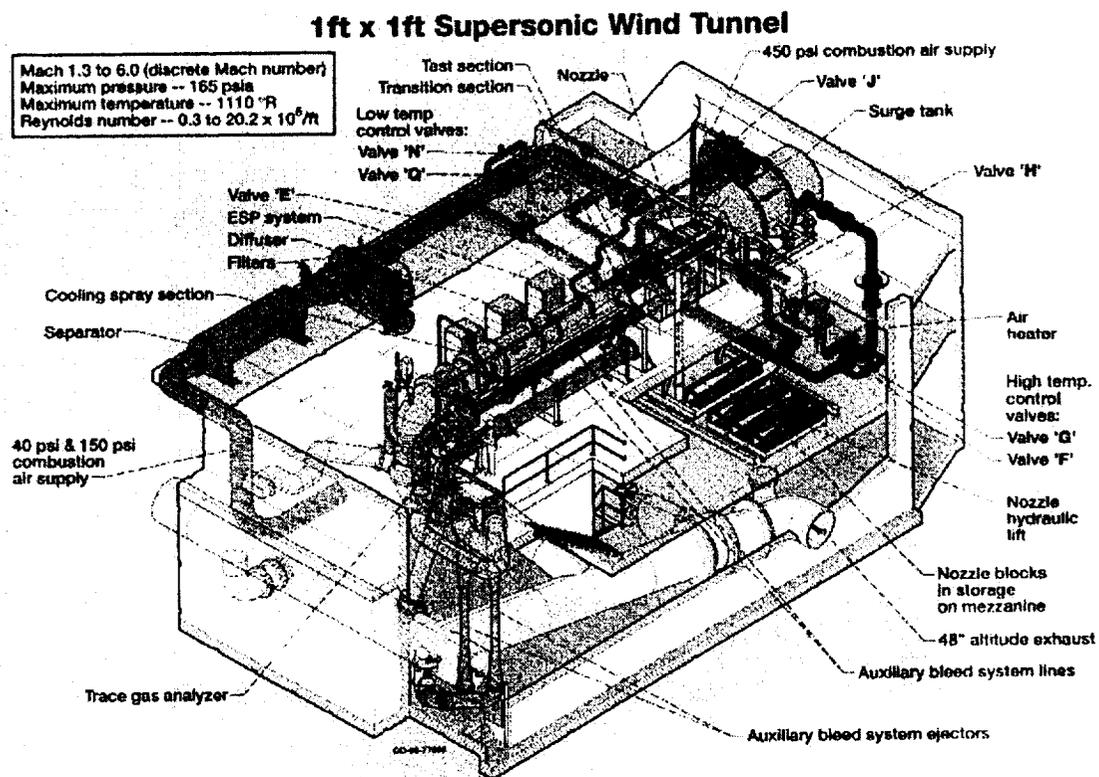


FIGURE 2.1 – Isometric cut-away view of the 1 by 1 ft Supersonic Wind Tunnel

supplied to the facility on a continuous basis from remotely located compressor equipment. Incoming air passes through a cyclone separator and a 1.5 micron filtration system before being routed to either the cold air circuit or the heated air circuit. The cold air circuit was originally made from 24" diameter carbon steel pipe and uses valves N and Q for pressure throttling. The heated air circuit was originally made from 10" diameter carbon steel pipe and uses valves F and G for pressure throttling. Both the cold and heated air circuits feed into the carbon steel surge tank where flow straighteners and screens condition the air for injection into the supersonic nozzles just upstream of the test section.

A photo of the surge tank is shown in Figure 2.2. It is constructed in three sections. The upstream section receives the incoming hot or cold air and acts as a settling chamber. The center section contains a honeycomb flow straightener which is a welded structure made from 1044 1" square, 12" long tubes. Four 30 mesh stainless steel wire screens are mounted directly downstream of the honeycomb flow straightener. The screens are tensioned by rod and spring assemblies mounted around the perimeter of the surge tank. The downstream section of the surge tank contains a rectilinear transition and bellmouth that terminates into a 12" by 12" opening. The opening feeds any one of eleven different supersonic nozzles ranging from Mach 1.3 to Mach 6.0.

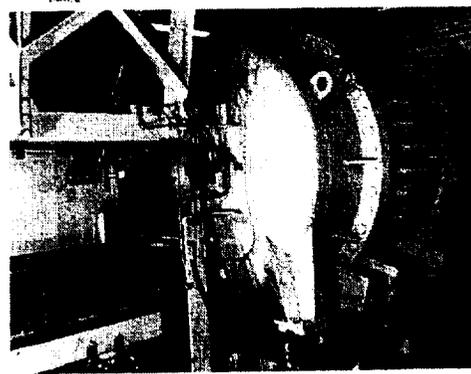


Figure 2.2 – Surge Tank with nozzle lowered to reveal 12" by 12" exit area.

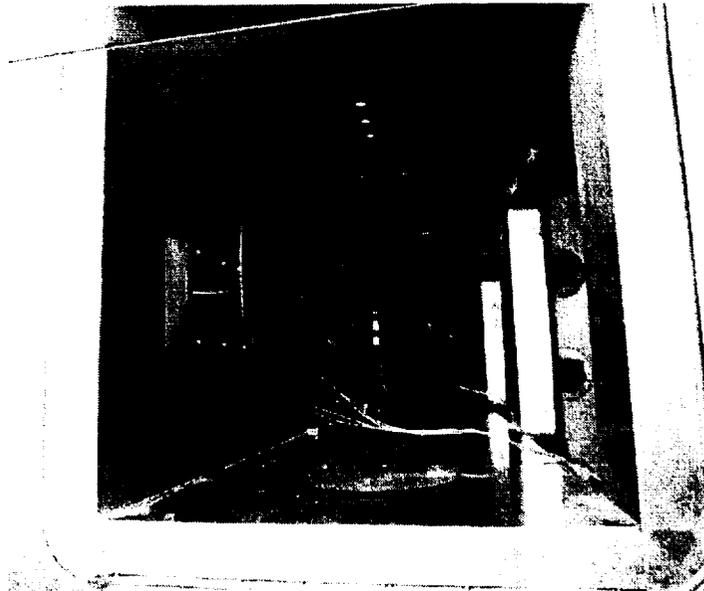
### **3.0 Problems Associated with Pipe Corrosion in Wind Tunnels**

There are a number of problems that can be related to pipe corrosion in wind tunnels. The problems can range from minor ones that are a mere nuisance, to more severe problems that can effect the safety of operation. Some of the problems include:

- **Reductions in Maximum Allowable Working Pressures (MAWP):** Severe corrosion over a long period of time can reduce the wall thickness of piping systems such that the MAWP would have to be reduced to meet ASME B31.3 specifications.
- **Valve Seat Wear:** Rust particles can create excessive wear on the seats of control valves. This can increase operational costs due to the need for premature rebuilding of the valves and the associated facility down time.
- **Research Data Quality:** Rust particles that become entrained into the air flow can eventually find their way to the test section. In supersonic wind tunnels, they are accelerated to high speeds and may impact instrumentation hardware such as pitot probes or thermocouples. The particles can become lodged inside small pressure tubing and may partially or totally block the pressure transducers ability to sense

pressure. Also, to some extent, the simple presence of the entrained particles may effect the quality of the flow field in the test section. This could cause local unsteadiness in the uniformity of the Mach Number and air flow angularity.

- **Abrasion to Test Articles:** Particles in the air flow can damage leading edge surfaces of the test article. Over a period of time, even harder materials such as steels can become “wire brushed”. Softer materials, such as the plastics used for wire insulation, can tear and possibly compromise research data.
- **Residual Dust:** From experience at the 1X1 Supersonic Wind Tunnel, most of the rust particles that are larger than 10 microns are swept down through the test section never to be seen again. However, smaller particles can become attached to the test section walls and model surfaces leaving behind a powdery red-brown film. An example of this can be seen in figure 3.1. Note how the residual dust on the left side wall traced the shocks coming off of the base of the model.



**Figure 3.1 – Residual dust can be seen on the ceiling and side wall of the 1X1 SWT test section after about 50 hours of run time.**

#### **4.0 Detection and Evaluation of Pipe Corrosion**

Initially, the severity of the piping corrosion problem at the 1X1 SWT was not realized until a model coated with a pressure sensitive paint was installed into the test section. Within seconds after the tunnel was started, the pressure sensitive paint was badly damaged. On repeated attempts, it was found that as long as the model was located near the tunnel walls or ceiling, that little damage, if any, was made to the pressure sensitive paint. However, as soon as the model was moved into the core flow area, the paint would quickly become shredded.

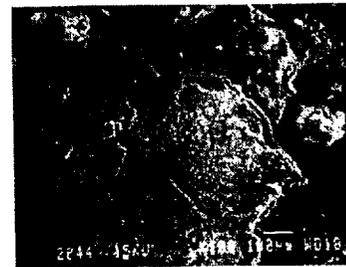
At this time, it was noticed that some larger particles had settled into the bellmouth of the surge tank. These were picked up by a swatch of carbon tape and analyzed using dispersive X-ray spectroscopy. This revealed that the elements in the particles were primarily aluminum, oxygen,



**Figure 4.1 – Particles that had settled in bellmouth of plenum, magnified 25X.**

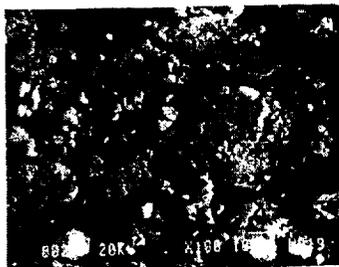
silicon and iron. The largest particles measured approximately 1000 microns long. A magnified view of the sample is shown in figure 4.1.

Another particle carbon tape sample was taken from the inside of the 24" carbon steel pipe. Physical access was gained through a service hatch just downstream of the filters. A dispersive X-ray spectroscopy analysis revealed, as expected, that iron and oxygen were the primary components. The largest particles measured approximately 500 microns long. A magnified view of the sample is shown in figure 4.2.



**Figure 4.2 – Rust particles from inside the 24" pipe, magnified 100X.**

To help determine the source of the particles that were entrained in the air flow, carbon tape was mounted into the center of the test section and the tunnel was run for about 5



**Figure 4.3 – Particles after impacting carbon tape in the test section at Mach 2.5, magnified 100X.**

minutes at Mach 2.5. The tape captured the sample shown in Figure 4.3. After impacting the carbon tape, the largest particles measured approximately 50 microns long. The dispersive X-ray spectroscopy analysis yielded the same element signature as the rust particles taken from the inside of the 24" pipe with the addition of a small amount of aluminum. Hence, it was determined that pipe corrosion was the primary source of the particles in the air flow.

To determine the extent of the pipe corrosion in the air supply systems of the 1X1 SWT, a boroscope was inserted through various pressure transducer and thermocouple ports. It was found that almost all of the interior surfaces of the 24" pipe and 10" pipe sections were severely rusted. Inside the surge tank, about 40% of the inside surfaces still had the original aluminum based paint while the remaining 60% was completely covered with rust.

## **5.0 Corrosion Repair Options and Costs**

Three corrosion repair options were considered. These are summarized in Table 5.1.

| <b>Option</b> | <b>24" Pipe (55ft lg)</b> | <b>10" Pipe (150ft lg)</b> | <b>Surge Tank</b> | <b>Honeycomb Section</b> | <b>Flow Screens</b> | <b>Estimated Cost</b> |
|---------------|---------------------------|----------------------------|-------------------|--------------------------|---------------------|-----------------------|
| <b>1</b>      | Replace with SS           | Replace with SS            | Replace with SS   | Clean and Nickel Plate   | Replace with SS     | \$450K                |
| <b>2</b>      | Clean and Nickel Plate    | Replace with SS            | Clean and Paint   | Clean and Nickel Plate   | Replace with SS     | \$170K                |
| <b>3</b>      | Clean and Paint           | Replace with SS            | Clean and Paint   | Clean and Nickel Plate   | Replace with SS     | \$135K                |

Option 1 offered the best long-term corrosion protection. All piping components and the surge tank would be replaced with new stainless steel components. The honeycomb flow straightening section would be cleaned and nickel plated. However, this option was ruled out due to the high cost of replacing the 24" pipes and surge tank with new stainless steel components.

Option 2 offered some cost relief through refurbishment of the existing carbon steel surge tank and 24" piping. The 55 ft of 24" piping would be cut into 8 ft sections (to fit inside the plating tanks), have flanges welded at the new joints, then shipped out for cleaning and dipping into a nickel plating tank. The surge tank would be opened up, the internal surfaces cleaned and coated with a rust inhibiting paint. This option was ruled out due to the turn around time associated with cutting and shipping the 24" pipe sections to remote locations for cleaning and plating.

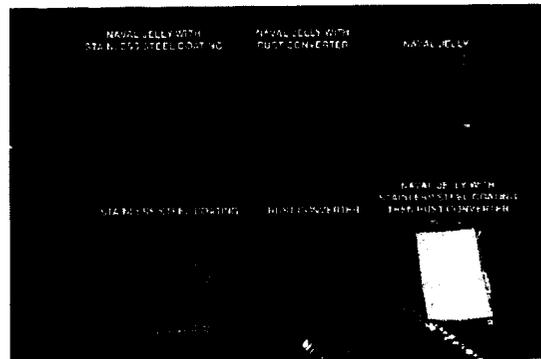
Option 3 was the least expensive option. It saved time and money by cleaning and coating the internal surfaces of the existing 24" carbon steel pipe sections. The pipe sections could be taken apart into 10 to 15 ft long sections, then cleaned and coated on the premises of the test cell. To work inside the 24" pipe sections, the personnel would need to be certified for confined spaces and might need to use respirators depending on the level of vapors.

## **6.0 Evaluation of Various Cleaning and Coating Processes**

To help determine the effectiveness and durability of various cleaning and coating processes and compounds, six test patches were applied to the inside of the 24" pipe. The test patches were combinations of three compounds: Naval Jelly, Rust Converter paint, and Stainless Steel High Temperature Coating. A photo showing the condition of the test patches after running the tunnel for four months can be seen in figure 6.1.

The Naval Jelly chemically removes rust from steel. It can be brushed on, and after ten minutes, wiped off with a damp cloth. The Naval jelly leaves behind a white film that acts as a passivation coating. The test patch using only the Naval Jelly displayed a recurrence of rust after the four month test period indicating a need for an additional rust inhibiting coating.

The Stainless Steel High Temperature Coating is rated for temperatures up to 1200° F, but requires baking at 400° F for 15 minutes to fully cure. It can be applied by brush or aerosol spray can. It was used in three of the test patches.



**Figure 6.1 – Six test patches were applied to the 24" pipe ID and tested for durability while running the tunnel over a 4 month period.**

The literature for the Rust Converter paint states that it “forms a chemical bond with steel and other metals to neutralize and chemically convert rust ... no need to sandblast or scrape”. The paint can be applied by brush or aerosol spray and is rated for temperatures up to 800° F without any need for baking.

With the exception of the Naval Jelly-only specimen, all test patches seemed to hold up fairly well. No noticeable corrosion or abrasion could be seen on the surfaces of the test patches.

It was decided to use the Naval Jelly / Rust Converter process for the refurbishment of the 24” pipe sections at the 1X1 SWT. The Rust Converter was chosen over the Stainless Steel Coating due to its ease of application (it didn’t need to be baked for a final cure). The Naval Jelly was also chosen due to its ease of application and the fact that it left behind a passivation coating and a sturdier, smoother surface once the loose rust particles were removed.

## **7.0 Piping Refurbishment**

To clean out and coat the inside of the 24” pipes, workers were required to crawl into them to apply the Naval Jelly and Rust Converter compounds. The 24” pipe sections were deemed to be a confined space. This required the workers to be OSHA certified for confined space entry and certified for the use of respirators. In addition, air blowers with non-explosive motors were needed for air ventilation.

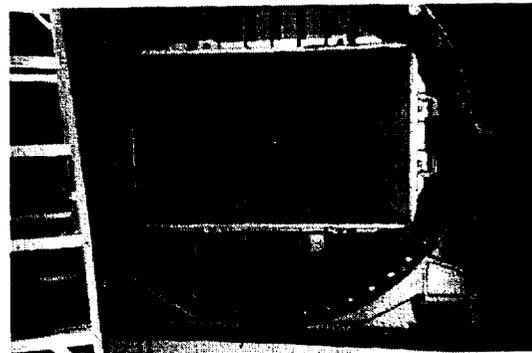


**Figure 7.1 – Two refurbished 24” pipe sections. Lengths were limited to 10’ – 15’ by cutting and installing bolted flanges.**

In order to make it a little easier for the workers, two of the 24” pipe sections were cut and bolted flanges were welded in place. This limited the total lengths of each pipe section to between 10’ and 15’.

## **8.0 Surge Tank Refurbishment**

In order to refurbish the surge tank, it was necessary to separate the center section from the upstream and downstream sections. The center section was moved sideways so as to provide access to the inside of all three sections. A photo of the center section is shown in figure 8.1.



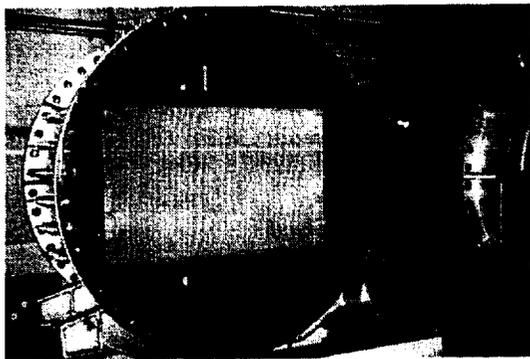
**Figure 8.1 – Center section of surge tank prior to refurbishment.**

Upon inspection, severe corrosion was found in the lower half of the surge tank. It is

believed that this was a result of water left behind after a hydrostatic pressure test that was performed on the surge tank in the late 80's. Also, about a 1/4" thick layer of rust particles carpeted the bottom of the surge tank. Apparently, the particles were blocked by the screens, then fell through the small openings between the screens and flow plates into the bottom of the surge tank. As with the 24" pipe sections, Naval Jelly and Rust Converter were used to clean and coat the interior surfaces of the surge tank.



**Figure 8.2 – The honeycomb flow straightener, made from 1044 1" square tubes, shown installed in the surge tank prior to refurbishment.**

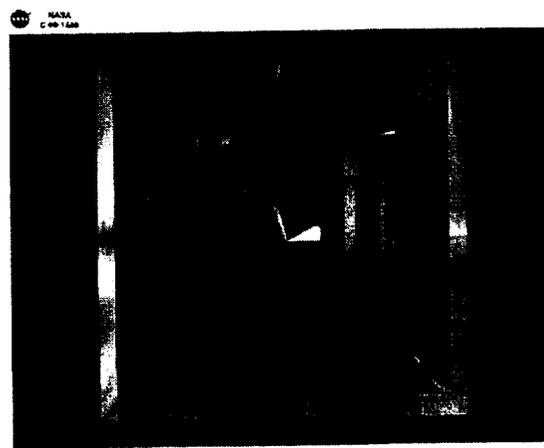


**Figure 8.3 – Refurbished surge tank.**

The honeycomb flow straightener, which was found to be severely corroded, is shown in figure 8.2. The honeycomb section was removed and cleaned by bead blasting. It was then electroless nickel plated in a dip tank. Likewise, twenty flow surface plates, which define the main flow boundaries inside the surge tank, were cleaned and nickel plated. Four new 30 mesh, stainless steel screens were purchased and installed. All fastening hardware inside the surge tank was replaced with new 304 stainless steel parts. The refurbished surge tank is shown in figure 8.3.

## 9.0 Subsequent Testing

After the 24" pipe sections had been refurbished, an inlet model was tested in the 1X1 SWT. Although the surge tank was not yet refurbished and the 10" piping was not yet replaced with stainless steel, a marked improvement in the air quality was observed. After about 20 hours of run time, no noticeable accumulation of residual dust was found in the test section. This would seem to indicate that the 24" piping was the main contributor of particles entrained in the air flow. This theory is supported by calculations which indicate that the



**Figure 9.1 – Test runs after refurbishment of 24" piping indicates a marked improvement in air quality.**

maximum air velocities in the 24" pipe sections are 5 times higher than that in the surge tank, and 2 times higher than in the 10" piping. The higher air velocities in the 24" piping would be more likely to pick up rust particles and carry them to the test section.

Once the refurbishment of the surge tank is completed, and the new stainless steel 10" pipe sections are installed, more tests will be run to quantify the improvement in air quality. As previously done, carbon tape will be installed in the test section in an attempt to collect particle samples. The density of the particles collected will be compared to samples taken prior to any refurbishment work, thereby providing a measurement of the percent improvement in the air quality.

## **10.0 Conclusions**

Although the best long term solution for pipe corrosion in air supply systems may be complete replacement with new stainless steel components, there are cost effective alternatives. Pipe sections of 24" diameter and larger can be directly accessed by workers for hand cleaning and coating operations. Parts up to 6' long (maybe more) can be chemically cleaned and nickel plated in dip tanks.

The trade-off in going with the cheaper cleaning and coating processes, is the uncertainty of the long-term durability of the coatings. However, test patches of the Naval Jelly / Rust Converter process held up very well over a four month test period at the 1X1 SWT. In the future, periodic visual inspections of the internal surfaces of the pipes will gauge the health of the coatings. Also, on occasion, carbon tape will be installed in the test section to catch any entrained particles that might be present, thereby providing a ongoing measurement of air quality.