Caul Plate Surface Treatment Effects on Infrared Heat Transfer for Hot Bonded Adhesive Repairs

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14. ABSTRACT

The Air Force Air Logistics Centers have a requirement to perform an elevated temperature metal bonded repair to aircraft. The heat is provided by heat lamps and must be driven thru a 1/4" aluminum caul plate. This report examines different surface treatments/coatings that can be applied to the caul plate to determine which is the best choice.

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TABLE OF CONTENTS

PURPOSE

To determine the best surface treatment/coating for heat transfer from a quartz heat lamp thru an aluminum caul plate to cure adhesive for a hot bonded on aircraft repair.

BACKGROUND

OO-ALC has a requirement to perform hot bonded repairs using quartz lamps as the heat source. The heat is transferred thru a 1/4" thick aluminum caul plate, thru the patch and into the adhesive bondline between the patch and aircraft structure.

TEST PLAN

Test locally available surface treatments/coatings in a set-up simulating the current operation and determine which one is the best choice to satisfy bondline temperature requirements for hot bonded repairs.

DISCUSSION

OO-ALC's requirement is to raise the bondline temperature to 200 to 250°F; the higher the temperature, the shorter the cure time. Higher temperature cures are preferred for production flow and to complete the cure cycle during one 9-hour shift. The experiment took a dual approach: Determine the temperature requirements at the monitoring thermocouple (closest to the heat source) to obtain 220°F in the bondline; and determine the maximum bondline temperature when full heat was applied with the quartz lamps.

Several coatings or surface conditions were tested. All tests were accomplished on 6" X 6" x 0.250 thick aluminum sheet stock. Figure 1 shows and lists the surface coatings/conditions of the test panels. The following is a detailed list of equipment and supplies used during the test:

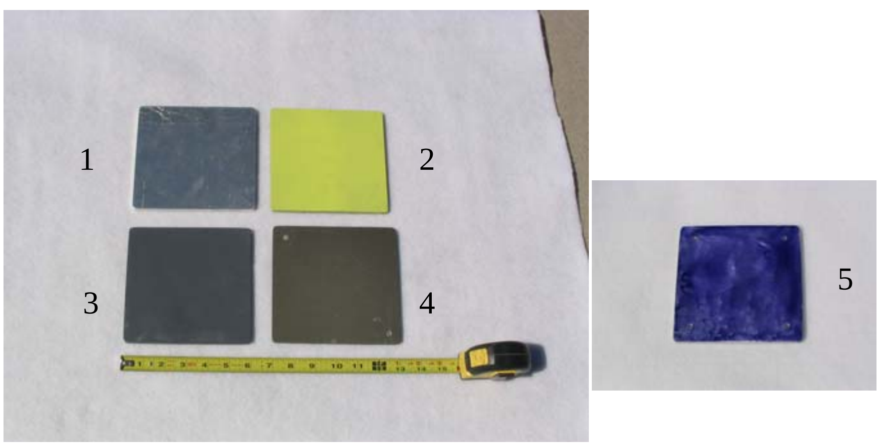
- Caul Plate (6 each), Aluminum, 2024-T351, 6" X 6" X .250"
- L-Angle, 6061-T6, 1.5" X 1.5" X .125" thick, 24" Long
- Flashtape: Richmond Aircraft Products # Flashtape 1; 1 mil polyester.
- Aluminum Tape, 3M#425 Shiny Silver, 4.5 mil
- Thermocouple Type J, locally manufactured from Heatcon HCS 1353 connector and VacTyte F8 Wire
- Hot Bonder, Heatcon 9200
- Heat Lamp (2 ea), Infratech Model SUF-3215, 120 Volts, 1500 Watts
- Bulb for heat lamp (2 ea), Infratech part # 10-1065 (E-1512)

Four thermocouples (TC) were placed on the side of the caul plate facing the heat lamp; these thermocouples are often referred to as "control TCs" because they are used to control the hot bonder during the heating cycle. For each TC, one 5/8" X 5/8" piece of flash tape was placed on the caul plate. The TC was placed and then covered with a piece of 3/4" X 3/4" flashtape. Two of the 4 were then covered with a 1"X1" piece of aluminum tape; this was done to determine the differences in thermocouple readings based on the type of tape covering the TC.

Figure 2 shows the set-up of the thermocouples exposed to the heat lamp. The TCs were placed in the same location on each sample. Additional thermocouples were placed at other points to collect data; these are shown in the data at the end of the report.

Initially, one of the TCs covered with aluminum tape was selected as the control TC for the hot bonder (as opposed to averaging the TCs). However, during the first run on the hard anodized caul plate with the dwell temperature set to 220°F, a cyclical heating/cooling pattern was evident. The hot bonder would direct power to the heat lamps until 221°F was indicated on the control TC. Over the next 3-5 minutes, the control TC temperature reading climbed to 225°F. It would then begin falling. Once 219°F was reached, the hot bonder would again supply power to the heat lamps. The control TC reading would fall to 215°F over the next few minutes then begin rising. The cause can be attributed to the 1" X 1" aluminum tape covering the TC reflecting the infrared heat away from area immediately surrounding the TC and the time lag for the heat being absorbed in the area surrounding the aluminum tape to be conducted thru the aluminum to the area under the aluminum tape and to the TC. To prevent this, a TC covered with flash tape was selected as the control thermocouple.

In all instances, the readings on the control TCs covered with aluminum tape (as opposed to blue flash tape) were closer to the bondline TC reading.



1 - As received aluminum
2 - Mil-PRF-23377 Type 1 Class C Epoxy Primer (yellow)
3 - Mil- PRF-85285 Polyurethane, Color 36118 (dark gray) applied over the epoxy primer
4 - Hard Anodize (natural - brown) per Mil-A-8625 Type III Class 1 Thickness unknown
5 - Machinist layout dye/bluing dye (indigo blue, semi transparent)
Abraded aluminum (not shown)

Figure 1 Surface Coatings/Conditions of Test Panels

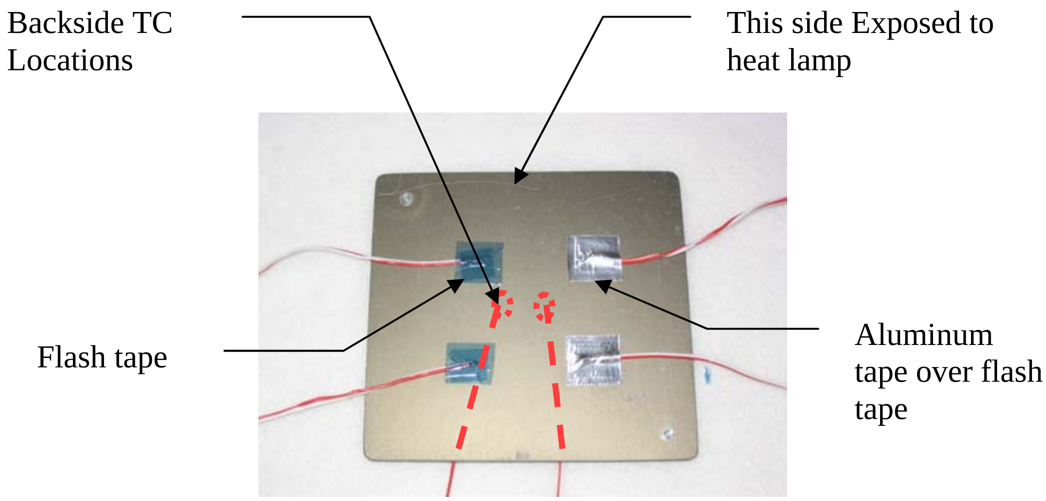


Figure 2 Thermocouple Placement

In order to simulate the actual process being used, a second 1/4" caul plate was bolted to the first to simulate an aircraft wing skin. Two L-Angles were attached to simulate aircraft substructure and heat sinks. Figure 3 details the set-up.

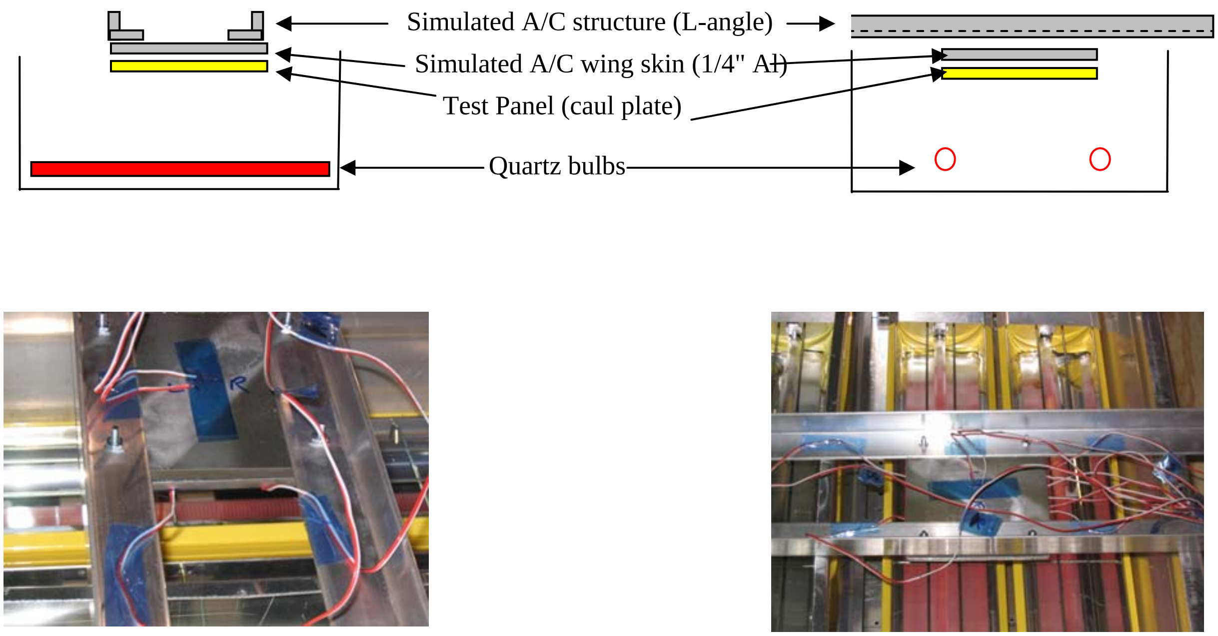


Figure 3 Test Set-up

The temperature of the control thermocouple was raised until both thermocouples in the bondline met or exceeded 220°F. Table 1 shows the averages of the thermocouple readings. Neither the bare aluminum nor the abraded aluminum achieved the minimum 220°F in the bondline.

The temperature of the control thermocouple was raised excessively high to determine the maximum attainable temperature for each type of coating/surface condition. Table 2 shows the averages of the thermocouple readings. Neither the polyurethane paint nor the primer were tested for maximum attainable temperature because their maximum sustainable service temperature is 250°F; this temperature was exceeded just to achieve the 220°F in the bondline.

A graphical representation of all the readings is shown in the data at the end of this report.

The machinist layout dye did not form a strong bond; when the tape holding the thermocouples was removed, the layout dye was removed; therefore, bluing dye should not be used because of the potential for the control thermocouples to become dislodged during the curing cycle.

Table 1: TC Readings of 220°F Bondline Thermal Survey

Surface Treatment	Flash tape (Surface)	Aluminum Tape (Surface)	Backside of Caul Plate (Bondline)
Bluing Dye	299	261	225
Primer	304	265	219
Hard Anodize	315	296.5	236
36118 Polyurethane Paint	310.5	298	236.5
Bare Aluminum			Didn't reach minimum
Abraded Aluminum			Didn't reach minimum

Table 2: TC Readings of Maximum Heating Thermal Survey

Surface Treatment	Flash tape (Surface)	Aluminum Tape (Surface)	Maximum Bondline Temperature Attainable (Backside of Caul Plate)
Hard Anodize	330	312.5	247.5
Bluing Dye	299	266	231
Abraded Aluminum	237	181.5	156
Bare Aluminum	215.5	156.5	141.5
36118 Polyurethane Paint			Not Tested
Primer			Not Tested

CONCLUSION

A hard anodized surface coating used on the caul plate is the best choice for heat transfer when using a quartz heat lamp. The ratio of the maximum bondline temperature increase (above ambient) for hard anodize compared to bare aluminum is 172 **:** 70; The hard anodized surface absorbed 2.5 times more heat!

Dark Gray Polyurethane paint color # 36118 and epoxy primer showed great potential; however, the maximum sustainable service temperature of the paint is 250°F per Mil-PRF-85285; the maximum sustainable service temperature for the primer is unpublished but believed to be around 250°F. Since the paint and/or primer is applied to a disposable caul plate, exceeding the max temperature may be acceptable; however, further investigation may need to be done to ensure the paint will not burn and/or pose a safety hazard if it is heated to over 250°F for extended periods of time.

Flash tape is the preferred method for covering thermocouples when using a heat lamp and the surface to be heated is colored. When aluminum tape is used on colored caul plates, a 3-5 minute lag in heat transfer to the control TC causes the hot bonder to cycle the heat on for a few minutes then off for a few minutes resulting in the surface temperature deviating +5°F then -5°F from the set point. In all cases, a thermal survey should continue to be conducted prior to the repair.

RECOMMENDATIONS

1. All units who use quartz heat lamps to drive heat thru a metal caul plate for hot bonded repairs should begin coating the surface of the caul exposed to the heat lamp to aid in efficient heat transfer. The preferred surface treatment is hard anodizing.

2. When applying thermocouples to a colored caul plate and using heat lamps, the thermocouples should only be covered with flash tape.

FURTHER RESEARCH

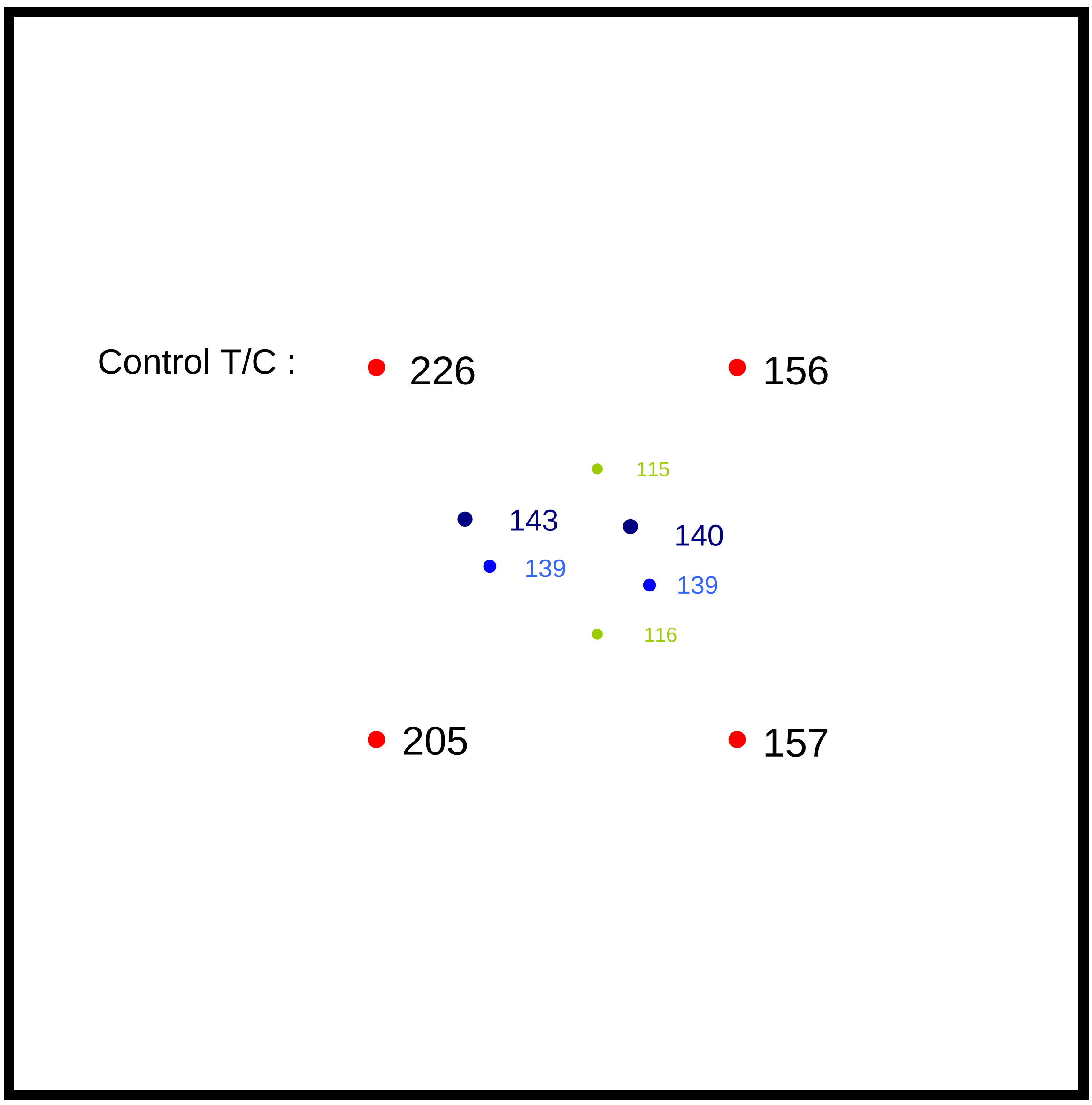
Further research could be conducted to determine if high temperature coatings (paints) are commonly used at the depots and how they fair against the coatings tested in this report.

Appendix A: Data

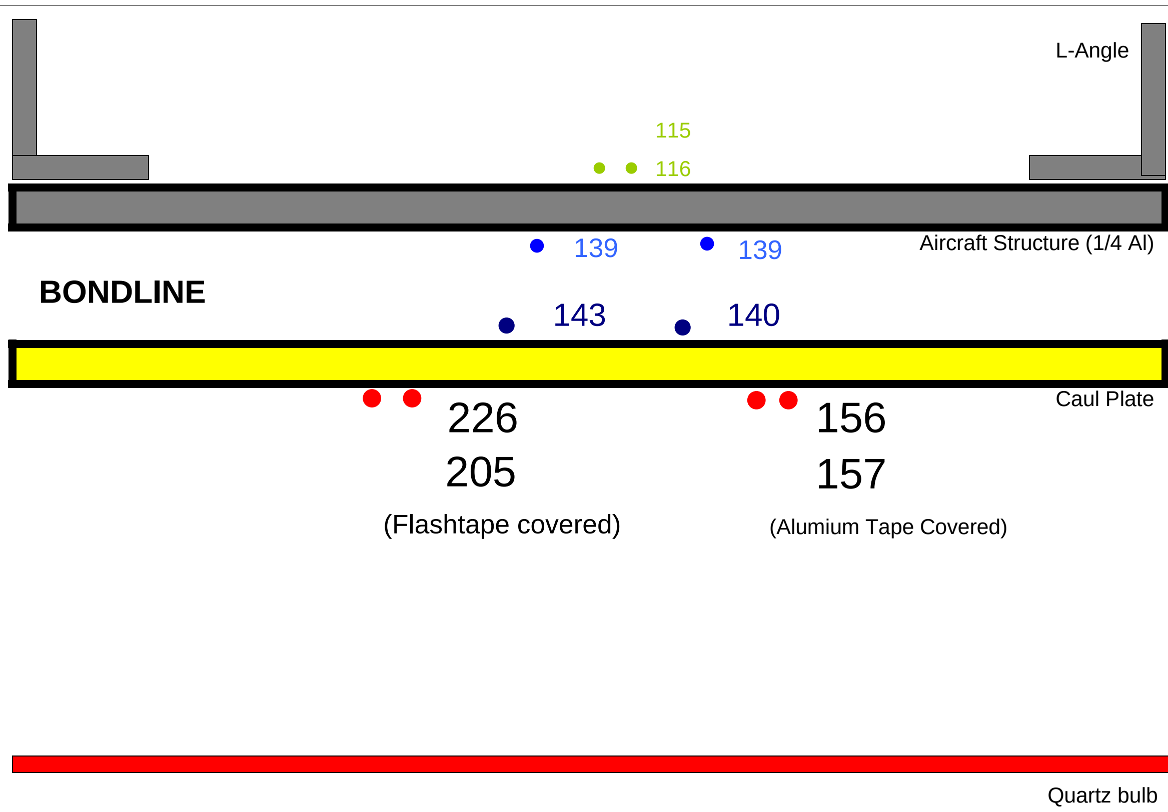
Surface Treatment: Bare Aluminum

Goal: Max Temp

Ambient Temp: 70



View Looking from heat lamp to caul plates. As numbers get smaller, they are further away from the heat lamp

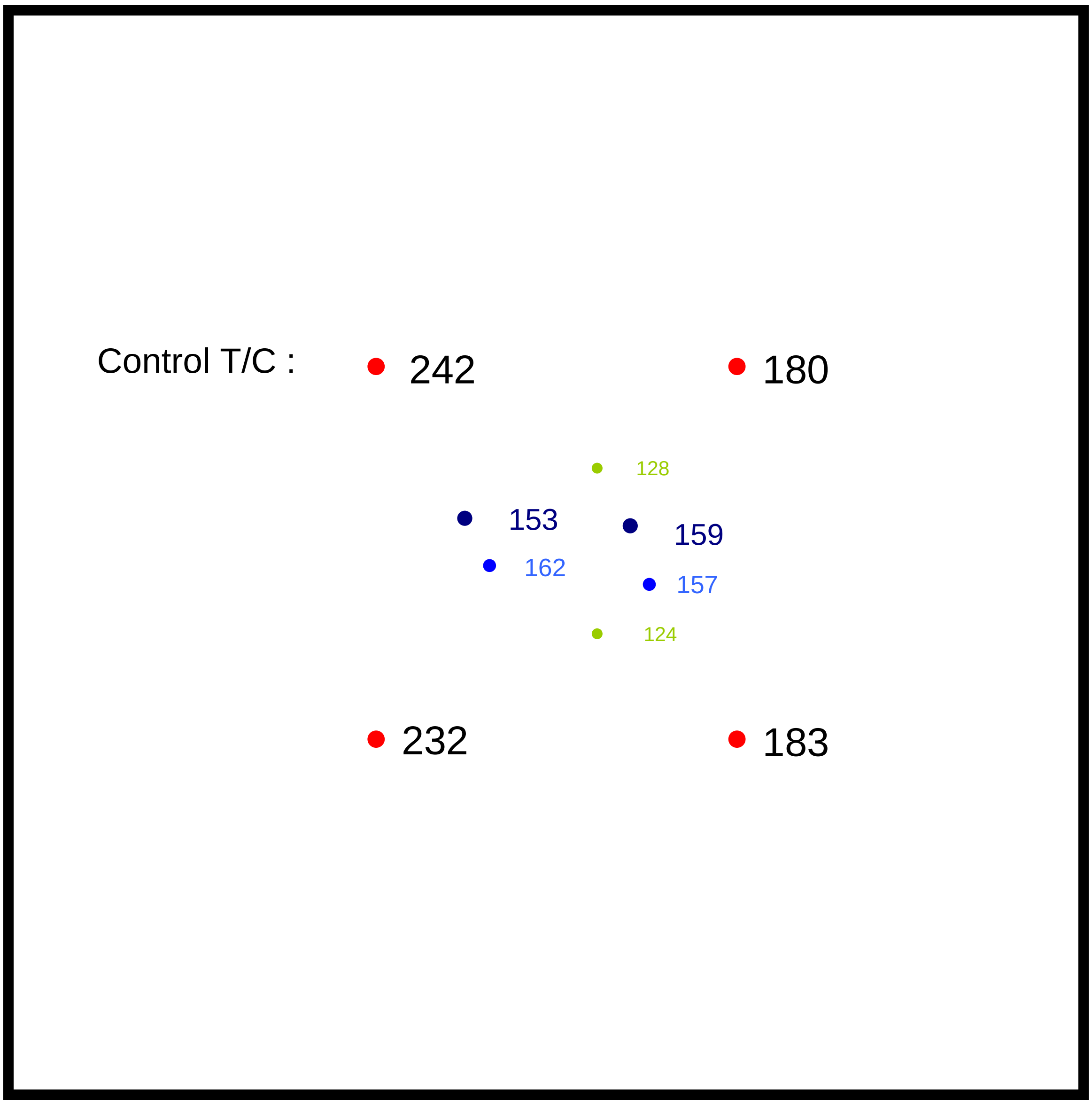


Profile view. Gaps have been distorted for better viewing. Fasteners are not shown.

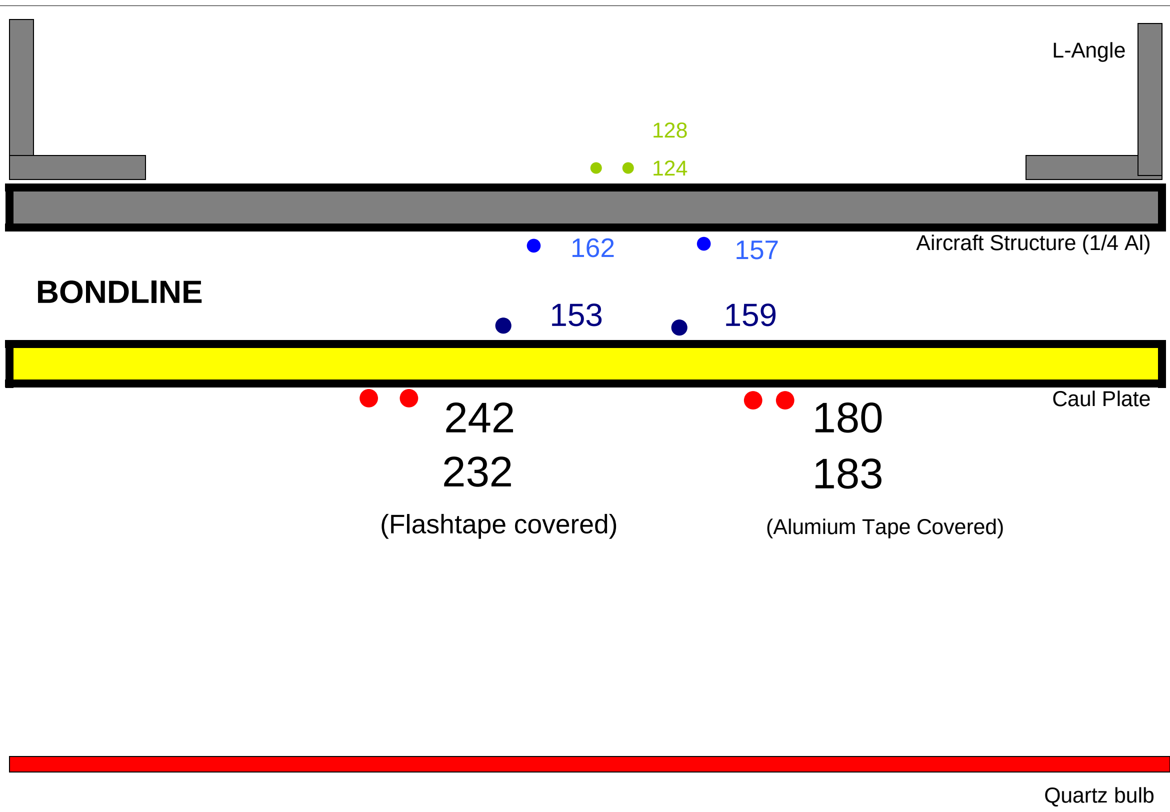
Surface Treatment: Abraded Aluminum

Goal: Max Temp

Ambient Temp: 73



View Looking from heat lamp to caul plates. As numbers get smaller, they are further away from the heat lamp

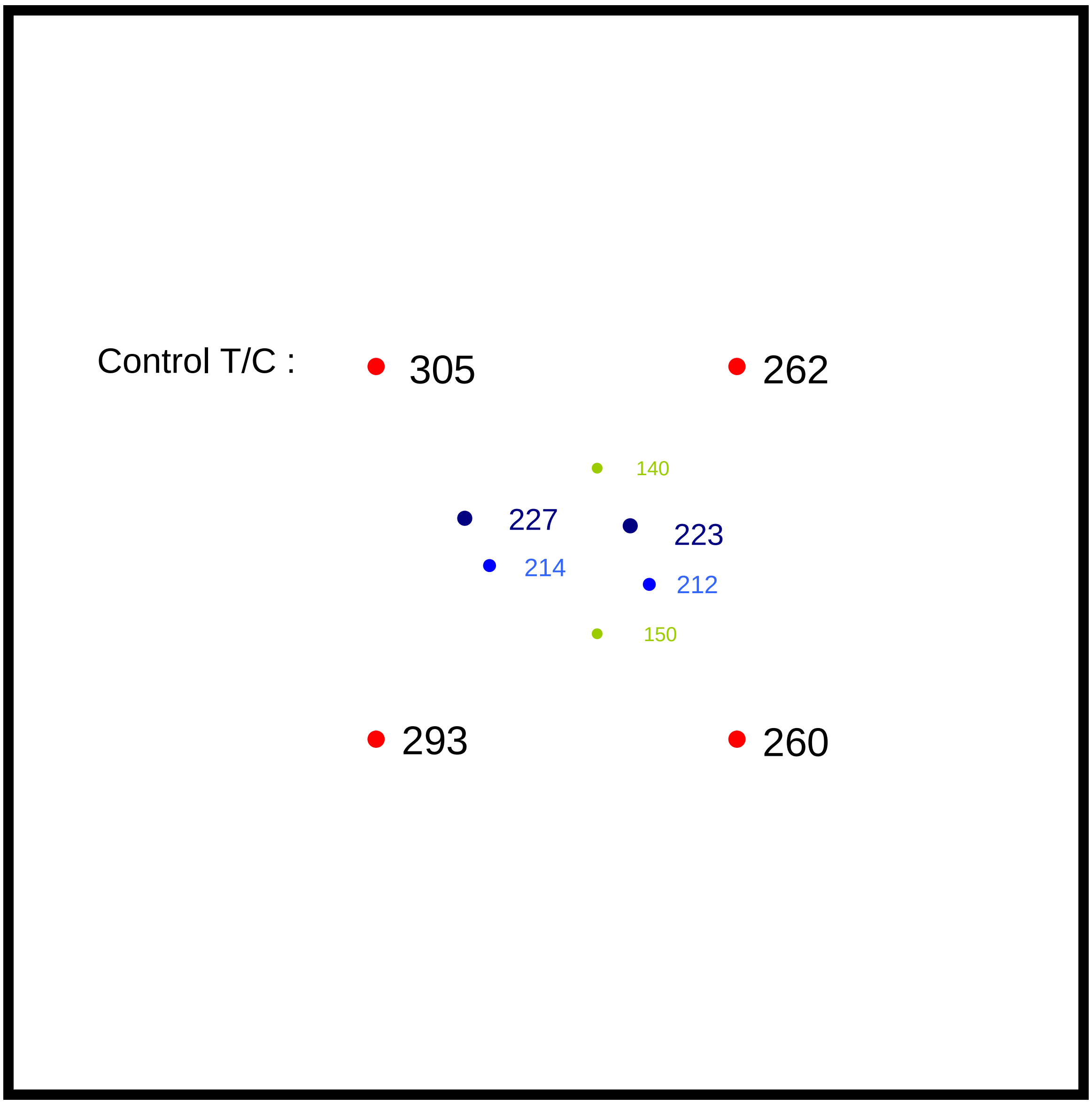


Profile view. Gaps have been distorted for better viewing. Fasteners are not shown.

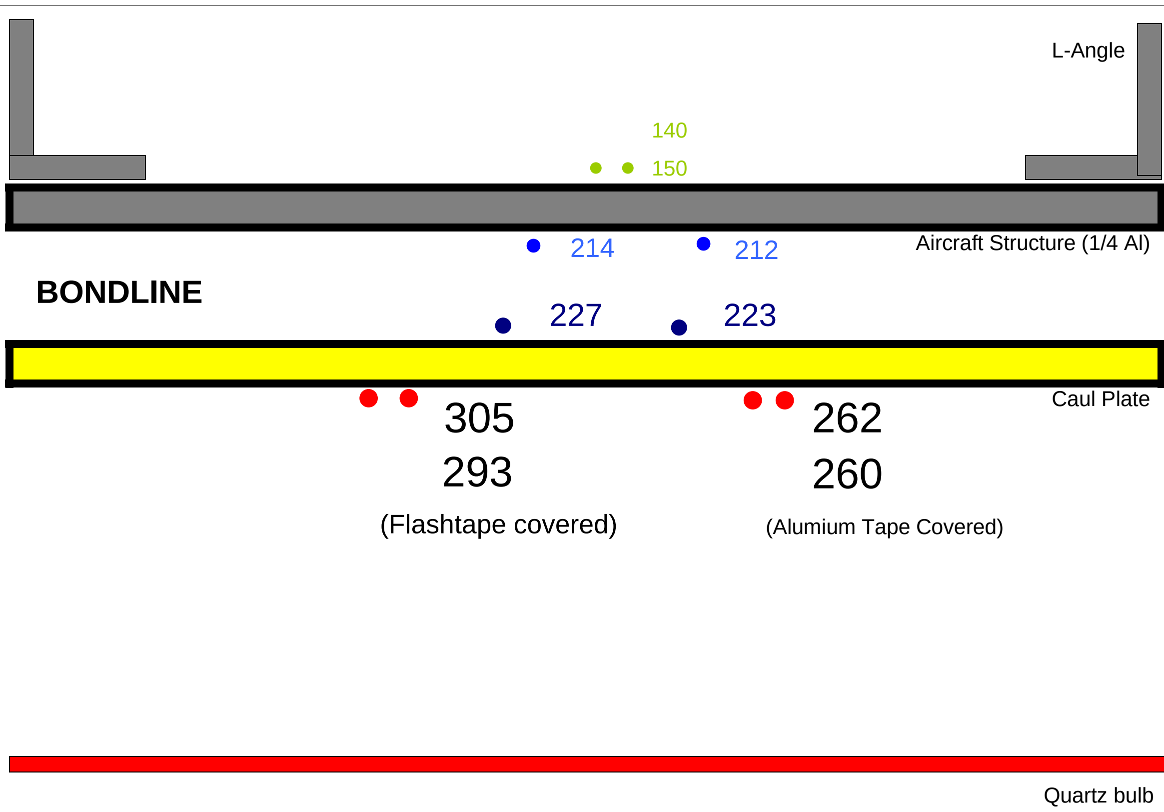
Surface Treatment: Bluing Dye

Goal: 220F Bondline

Ambient Temp: 73



View Looking from heat lamp to caul plates. As numbers get smaller, they are further away from the heat lamp

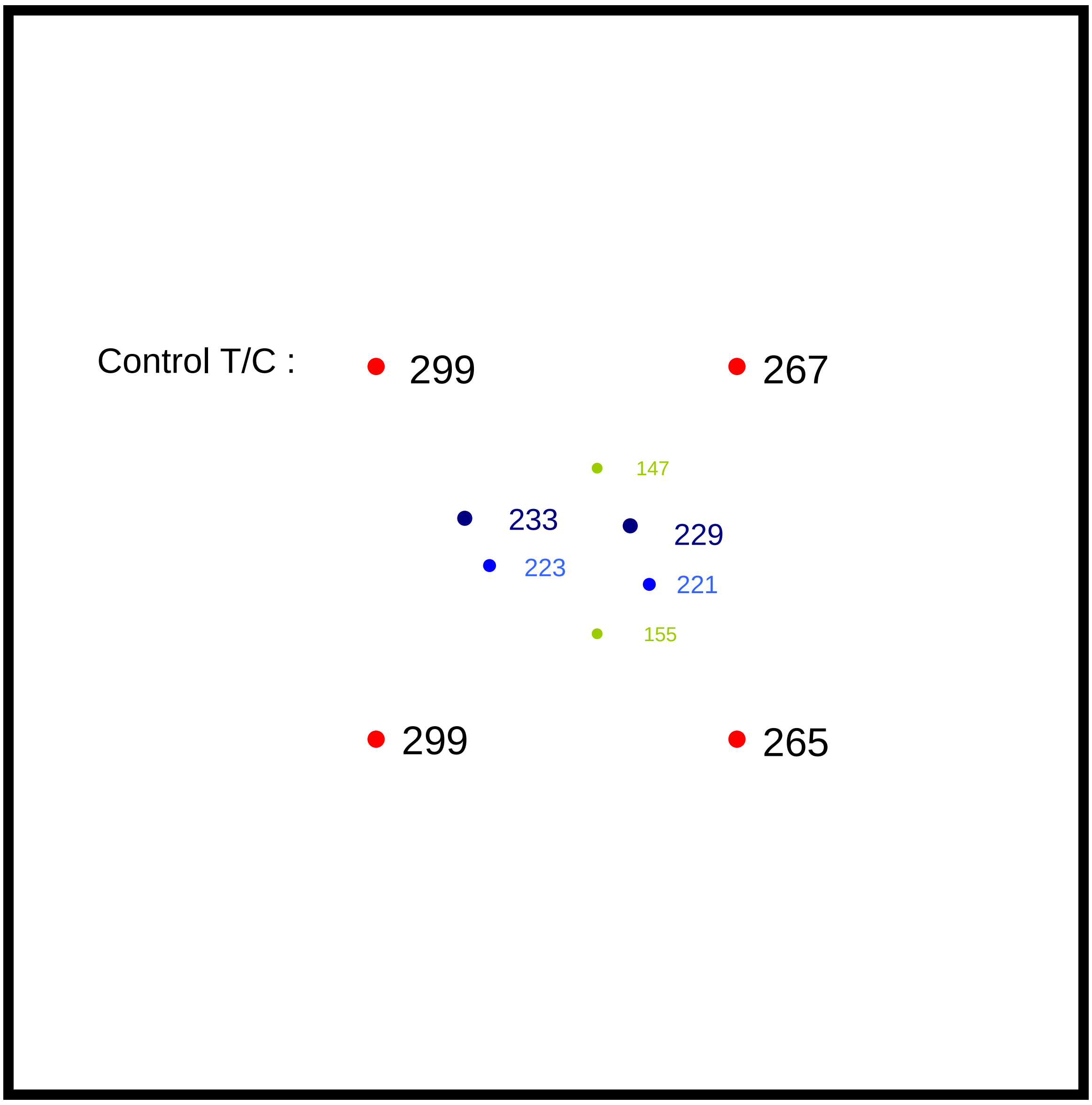


Profile view. Gaps have been distorted for better viewing. Fasteners are not shown.

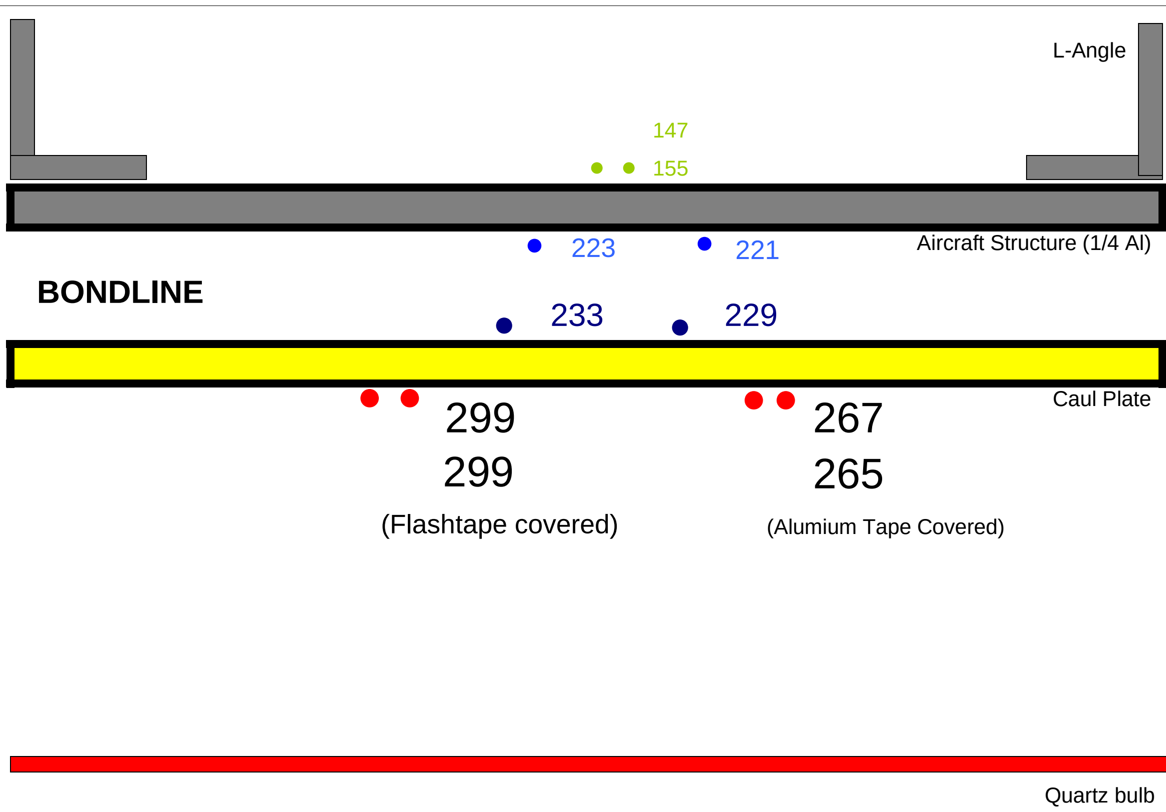
Surface Treatment: Bluing Dye

Goal: Max Temp

Ambient Temp: 0



View Looking from heat lamp to caul plates. As numbers get smaller, they are further away from the heat lamp

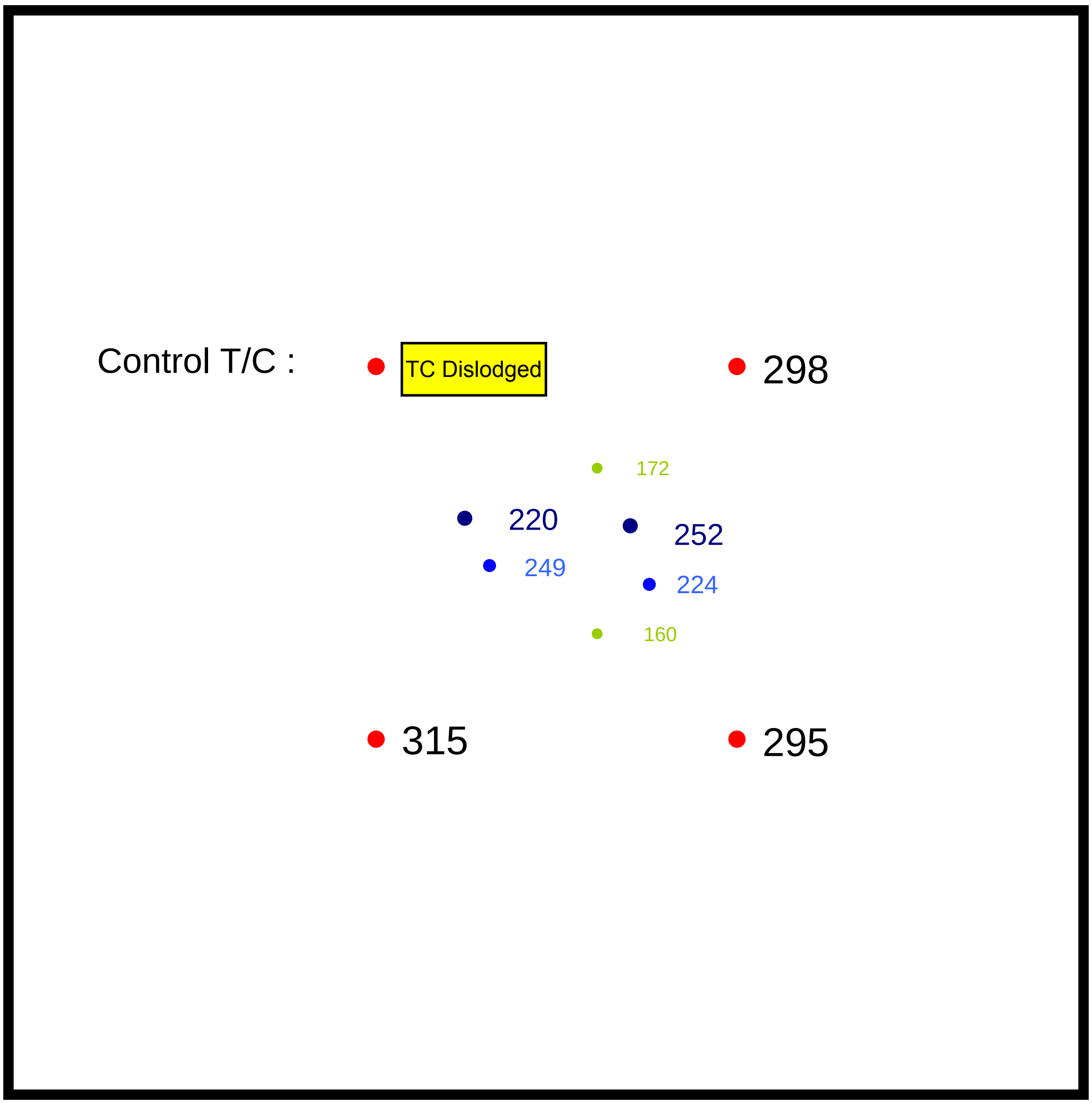


Profile view. Gaps have been distorted for better viewing. Fasteners are not shown.

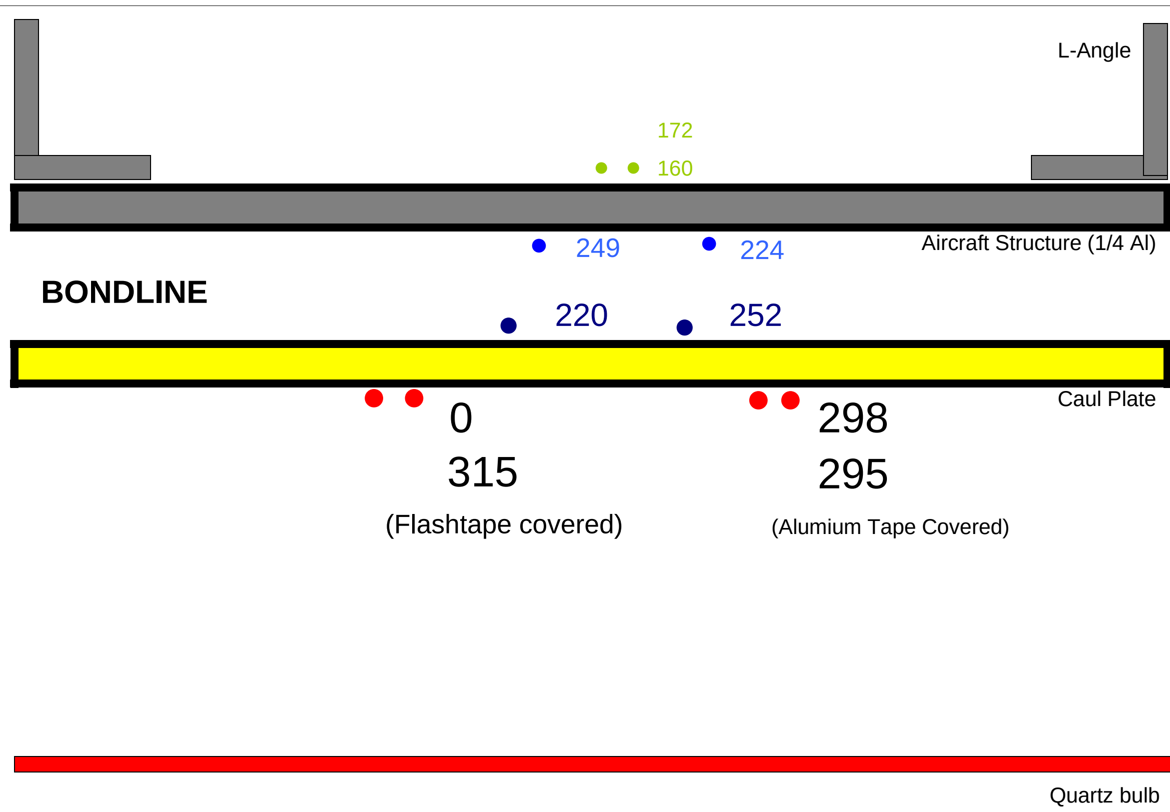
Surface Treatment: Hard Anodize

Goal: 220F Bondline

Ambient Temp: 75



View Looking from heat lamp to caul plates. As numbers get smaller, they are further away from the heat lamp



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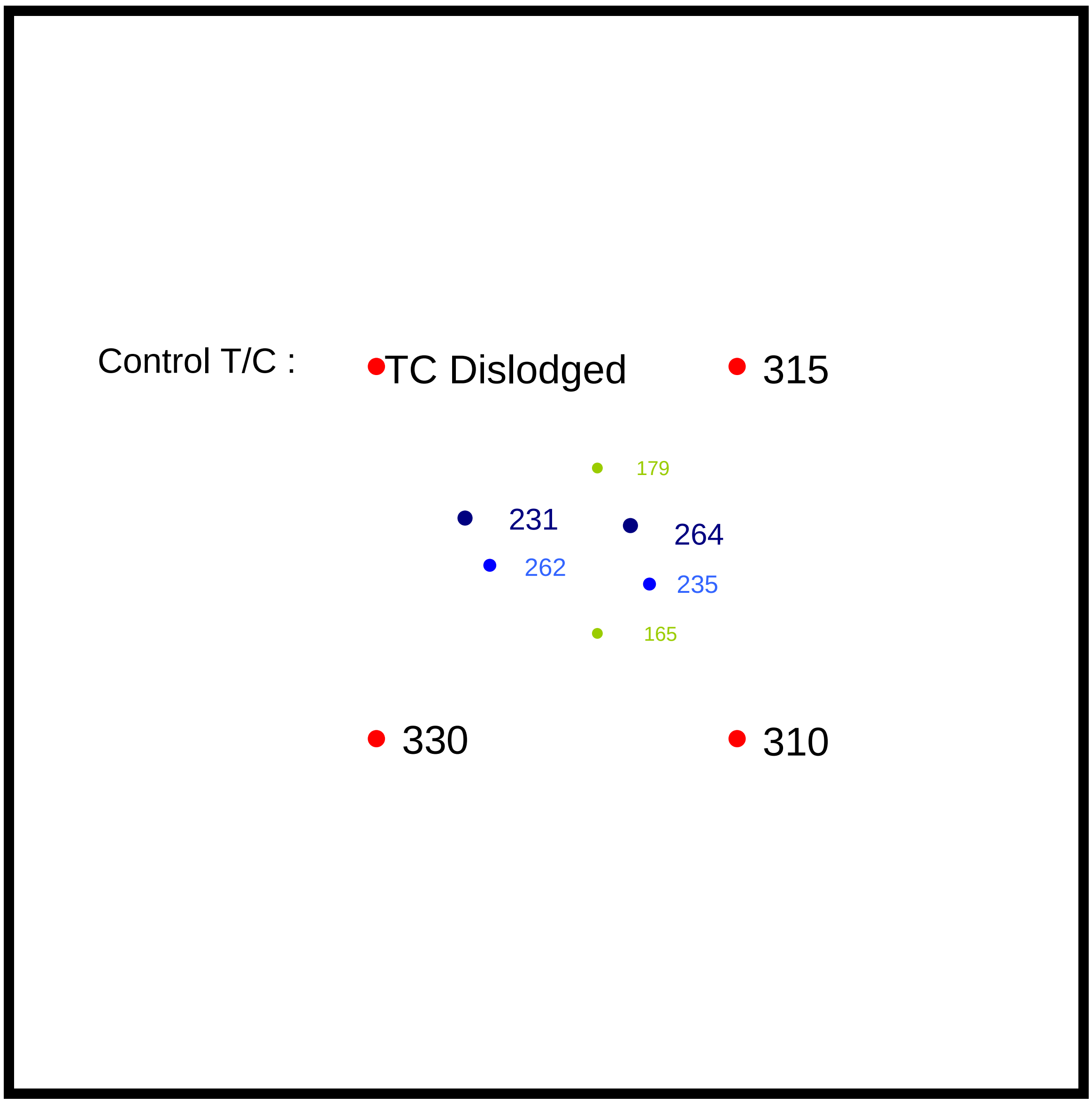
Surface Treatment: Hard Anodize

Goal: Max Temp

Ambient Temp: 75



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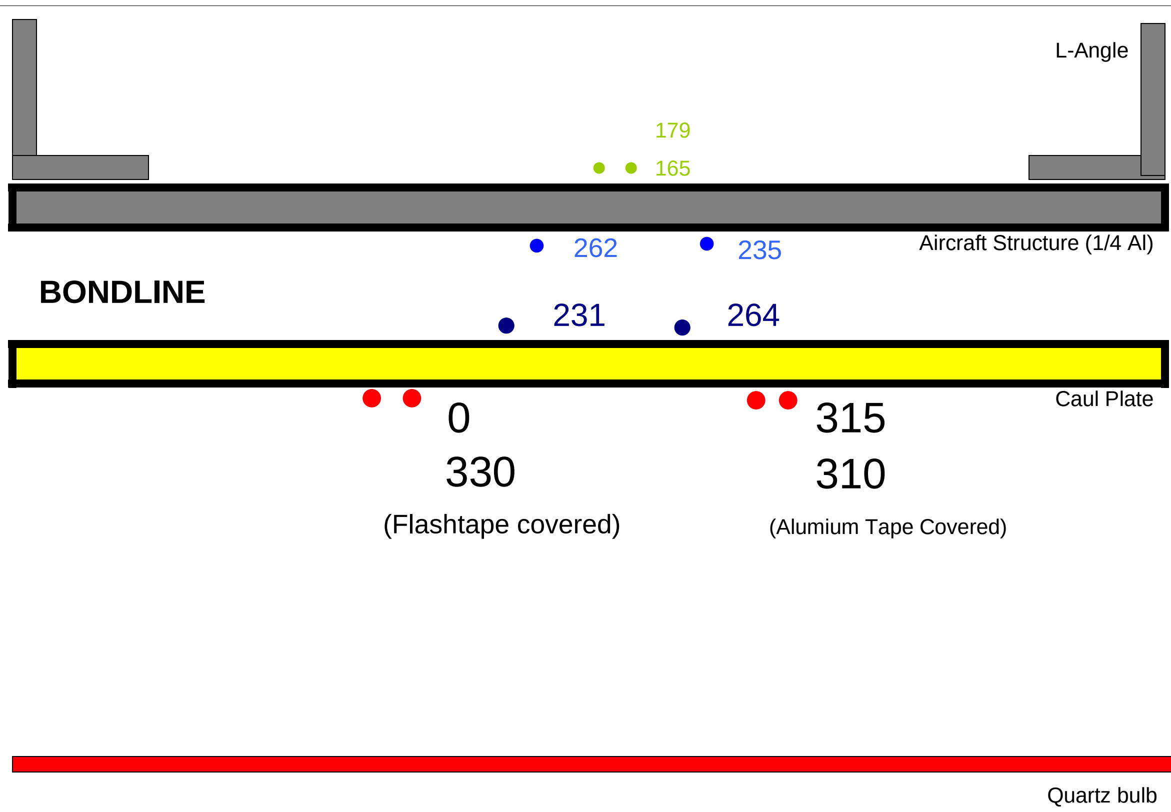
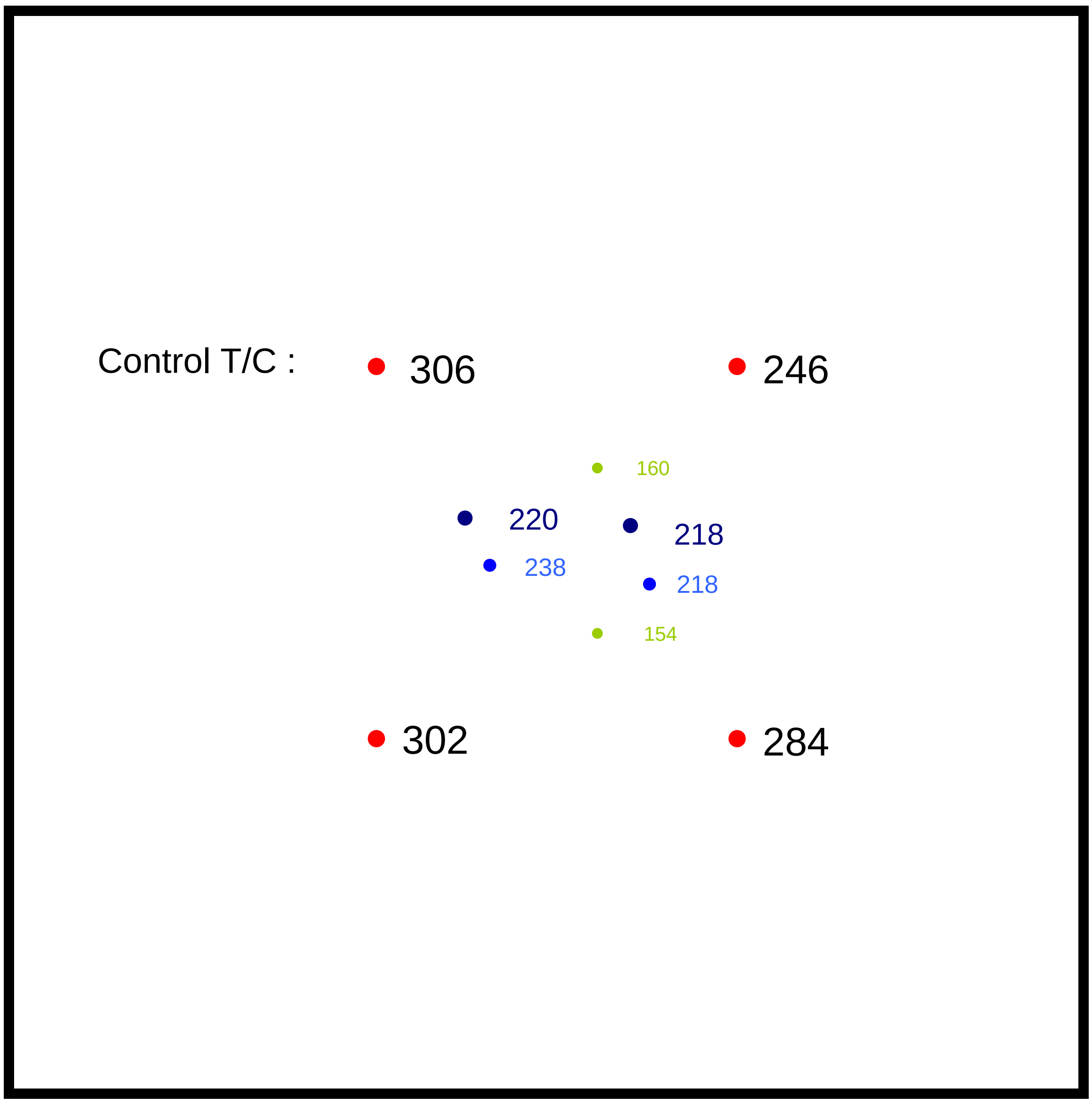


Profile view. Gaps have been distorted for better viewing. Fasteners are not shown.

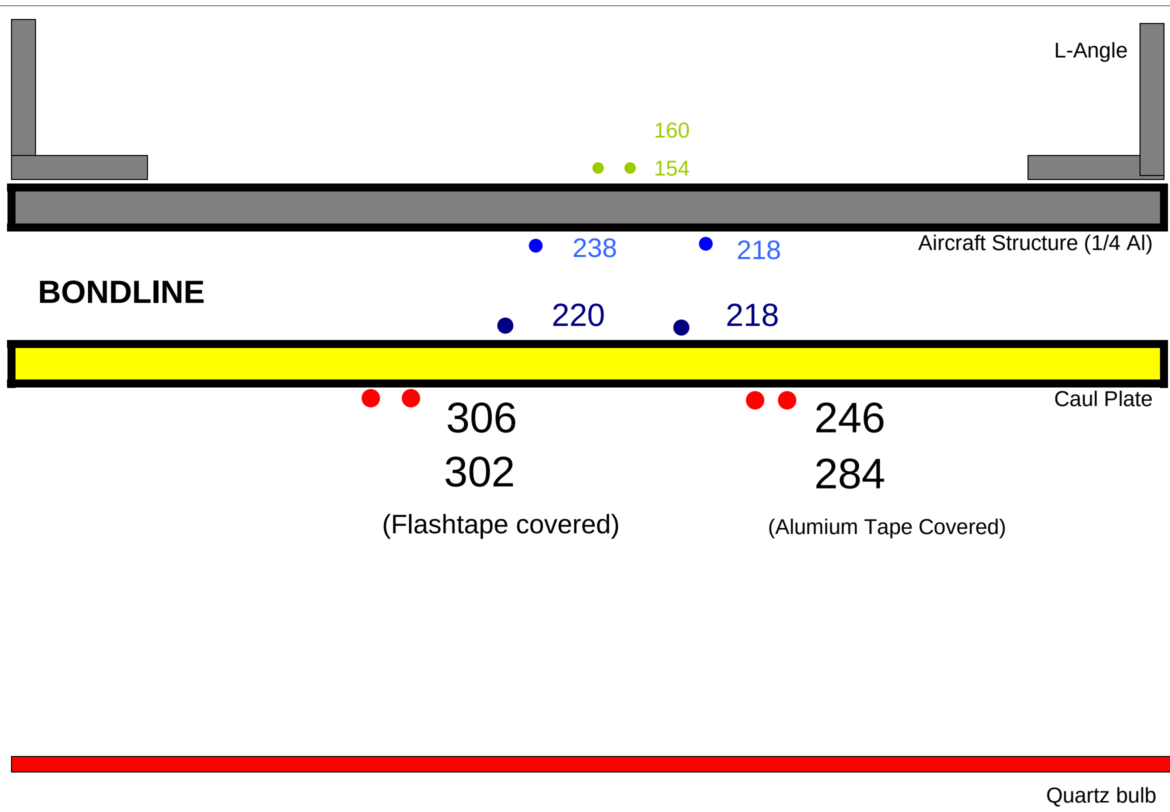
Surface Treatment: Primer

Goal: 220F Bondline

Ambient Temp: 302



View Looking from heat lamp to caul plates. As numbers get smaller, they are further away from the heat lamp

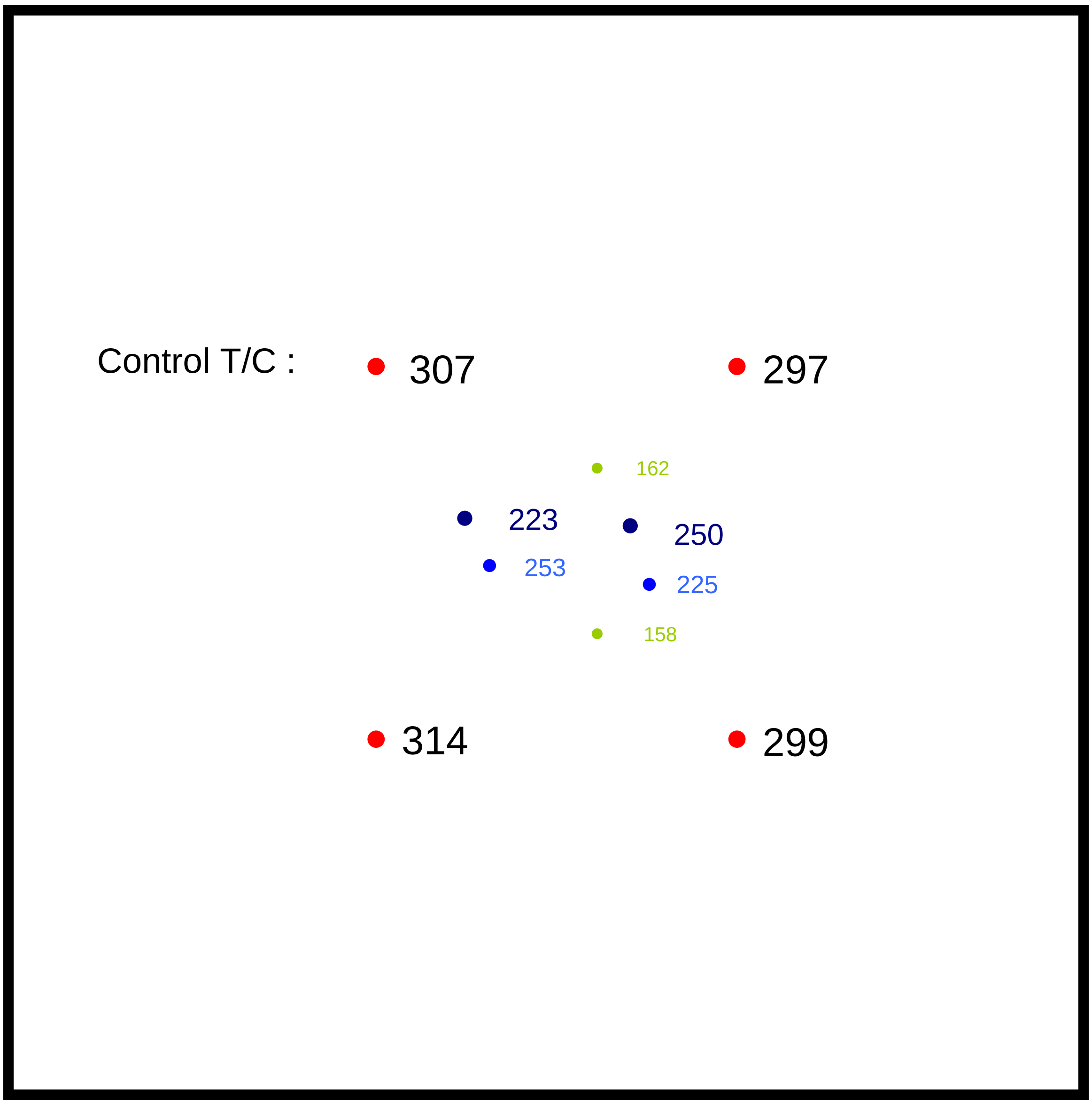


Profile view. Gaps have been distorted for better viewing. Fasteners are not shown.

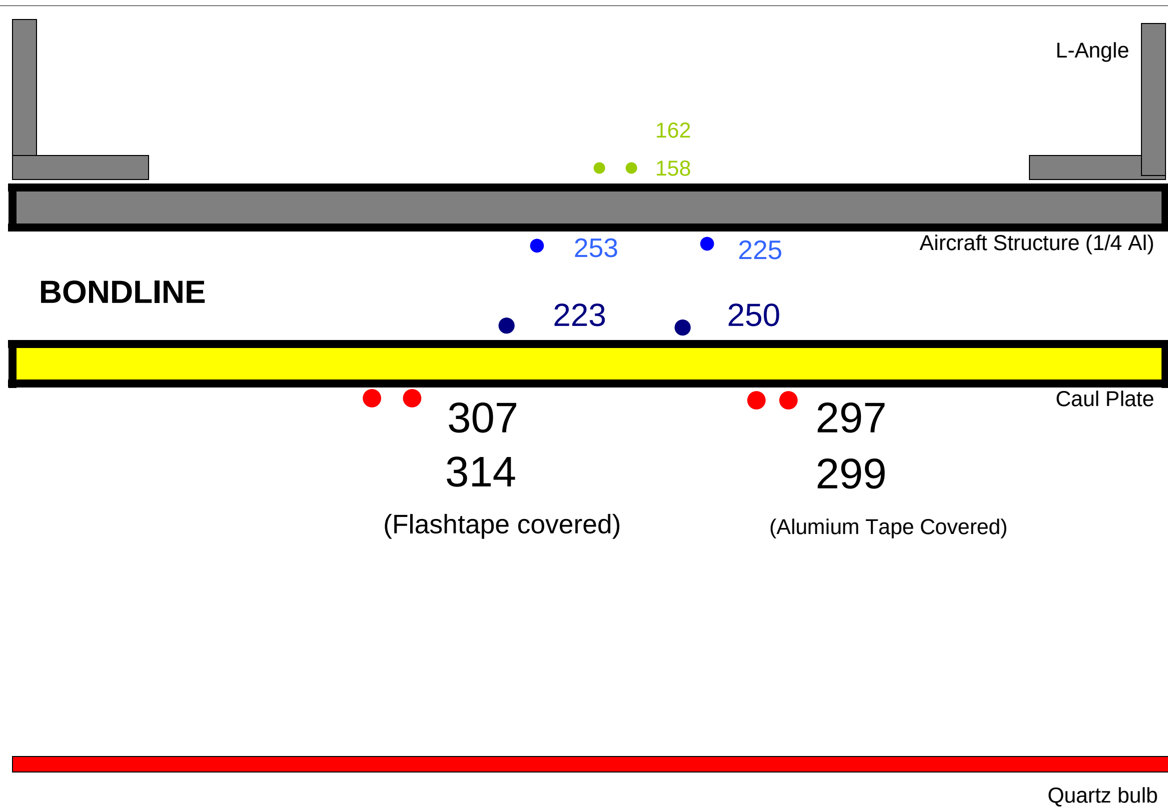
Surface Treatment: 36118 Polyurethane

Goal: 220F Bondline

Ambient Temp: 74



View Looking from heat lamp to caul plates. As numbers get smaller, they are further away from the heat lamp



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