BOMBARDIER
Toronto Site
PROPRIETARY INFORMATION

PPS 1.02

PRODUCTION PROCESS STANDARD

FORMING ALUMINUM ALLOYS

Issue 16 - This standard supersedes PPS 1.02, Issue 15.
- Vertical lines in the left hand margin indicate changes over the previous issue.
- Direct PPS 1.02 related questions to michael.wright@aero.bombardier.com.
- This PPS is effective as of the distribution date.

Prepared By:	*Michael Wright*	(Michael Wright)	September 14, 2015
	PPS Group		
Approved By:	*Ken Quon*, for	(Emma Donlin)	September 15, 2015
	Materials Technology		
	Anthony Assivero, for	(David Dawe)	September 29, 2015
	Quality		

Signed original on file. Validation of paper prints is the responsibility of the user.

Table of Contents

Section & Title **Page**

Tables

Figures

1 Scope

1.1 This Production Process Standard (PPS) specifies the procedure and requirements for forming of aluminum alloys.

1.1.1 This PPS complements the engineering drawings that specify its use as an authorized instruction. The procedure specified in this PPS must be followed to ensure compliance with all applicable specifications. In general, if this PPS conflicts with the Engineering drawing, follow the engineering drawing. The requirements specified in this PPS are necessary to fulfill the engineering design and reliability objectives.

1.1.2 Refer to PPS 13.26 for the subcontractor provisions applicable to this PPS.

1.1.3 Procedure or requirements specified in a Bombardier BAPS, MPS, LES or P. Spec. **do not** supersede the procedure or requirements specified in this PPS.

2 Hazardous Materials

2.1 Before receipt at Bombardier (Toronto Site), all materials must be approved and assigned Material Safety Data Sheet (MSDS) numbers by the Bombardier (Toronto Site) Environment, Health and Safety Department. Refer to the manufacturer's MSDS for specific safety data on any of the materials specified in this PPS. If the MSDS is not available, contact the Bombardier (Toronto Site) Environment, Health and Safety Department.

3 References

3.1 General

3.1.1 Unless a specific issue is indicated, the issue of the reference documents specified in this section in effect at the time of manufacture shall form a part of this specification to the extent indicated herein.

3.2 Bombardier (Toronto Site) Specifications

3.2.1 PPS 1.01 - Dimpling Aluminum Alloys.

3.2.2 PPS 1.03 - Hot Joggling of Aluminum Alloys.

3.2.3 PPS 1.06 - Tube Swaging.

3.2.4 PPS 1.08 - Magnetic Pulse Forming of End Fittings to Tubes.

3.2.5 PPS 1.34 - Magnetic Pulse Forming of Tubes (Expansion and Compression).

3.2.6 PPS 6.01 - Fabrication of Rigid Fluid Lines.

3.2.7 PPS 13.26 - General Subcontractor Provisions.

3.2.8 PPS 13.39 - Bombardier Toronto Engineering Process Manual.

3.2.9 PPS 20.03 - Fluorescent Penetrant Inspection.

3.2.10 PPS 23.01 - Designation of Wrought Aluminum Alloys.

3.2.11 PPS 27.01 - Repair of Surface Defects in Aluminum Alloy Sheet.

3.2.12 PPS 27.02 - Edge Finishing Aluminum Alloy Parts.

3.2.13 PPS 30.01 - Heat Treatment of Aluminum Alloys.

4 Materials, Equipment and Facilities

4.1 Materials

4.1.1 Unless otherwise specified in this section, use only the materials specified; use of superseding or alternative materials is not allowed.

4.1.2 SAE solvent soluble oils and grease.

4.1.3 Refer to PPS 23.01 for an explanation of the alloy designations, temper designations and material specifications of aluminum alloys.

4.2 Equipment

4.2.1 Refer to Table 1 for a listing of forming machine tool standards.

Table 1 - Forming Equipment Available at Bombardier (Toronto Site)

Forming Machine	Tool Standard		Forming Machine	Tool Standard
Asea Press	TS 237		Power Brake	TS 221
Buffalo Rolls	TS 251		Stretch Press (Hufford)	TS 234
Mechanical Press	TS 211			
Note: Refer to the Tool Standard indicated for information regarding form blocks, dies, intensifiers, etc.				

4.3 Facilities

4.3.1 This PPS has been categorized as a “Controlled Special Process” according to PPS 13.39 and as such only facilities specifically approved according to PPS 13.39 are authorized to perform forming of aluminum alloys according to this PPS.

4.3.2 Bombardier subcontractors must direct requests for approval to Bombardier Aerospace Supplier Quality Management. Bombardier Aerospace facilities must direct requests for approval to the appropriate internal Quality Manager.

4.3.3 Facility approval shall be based on a facility report, a facility survey and completion of a qualification test program, if required. The facility report must detail the materials and equipment to be used, the process sequence to be followed and the laboratory facilities used to show compliance with the requirements of this PPS. Any deviation from the procedure or requirements of this PPS must be detailed in the facility report. Based upon the facility report, Bombardier (Toronto Site) Materials Technology may identify additional qualification and/or process control test requirements. During the facility survey, the facility requesting qualification must be prepared to demonstrate their capability. Once approved, no changes to subcontractor facilities may be made without prior written approval from Bombardier Aerospace Supplier Quality Management.

4.3.3.1 Unless otherwise specified by Bombardier Aerospace Supplier Quality Management, for approval of subcontractor facilities to perform forming of aluminum alloys according to this PPS completion of a test program and submission of suitable test samples representative of production parts is required. Test samples must meet the requirements specified in section 6.

5 Procedure

5.1 General

5.1.1 The “orange peel” effect in stretching and deep drawing operations is caused through a critical amount of cold working followed by heat treatment or excessive heat treatment. Components prone to “orange peel” should be subjected to a “reversion treatment”. For 2024 material, this consists of 6 minutes at 390°F (199°C) followed by air cooling to room temperature. For other materials, consult Bombardier (Toronto Site) Materials Technology.

5.1.2 The W condition (as quenched) starts as soon as the part has completed the quenching cycle. Depending on the temperature at which the part is stored, the W condition can only be held for a limited time as specified in PPS 30.01.

5.2 Preparation of Parts

5.2.1 Before forming, edge finish parts according to PPS 27.02.

5.3 Forming

5.3.1 Except as otherwise noted herein, form parts according to the forming machine manufacturer's instructions. If practical, when loading the ASEA press or Niagara press, keep the form blocks all of a similar height. Keep any high blocks in the centre and arrange the blocks to prevent excessive rubber elongation. For forming, use lubricants which are not detrimental to the material and may be removed easily by vapour degreasing or water washing.

5.3.2 Unless otherwise specified on the engineering drawing, the bend radius for the material and temper as listed in Table 2 is the minimum that may be used for simple bends. If the engineering drawing specifies a bend radius less than the minimum specified in Table 2, submit the part for fluorescent penetrant inspection according to PPS 20.03 in the bend area after forming.

Table 2 - Standard Bend Radii

Material	Clad Alloy				Non-Clad Alloys				
	2024-O	2024-W 7075-O 7075-W	2014-T3 2024-T3 2024-T42	7075-T6 7075-T73	6061-O 6061-W	5052-32	6061-T4	5052-H34	6061-T6
0.016"	0.030"	0.03"	0.05"	0.09"	0.03"	0.03"	0.04"	0.04"	0.04"
0.020"	0.03"	0.04"	0.06"	0.10"	0.03"	0.04"	0.04"	0.05"	0.05"
0.025"	0.04"	0.05"	0.08"	0.12"	0.04"	0.05"	0.06"	0.06"	0.08"
0.032"	0.05"	0.06"	0.10"	0.15"	0.05"	0.05"	0.07"	0.08"	0.09"
0.040"	0.07"	0.08"	0.12"	0.20"	0.07"	0.07"	0.09"	0.10"	0.11"
0.050"	0.08"	0.09"	0.15"	0.25"	0.08"	0.08"	0.12"	0.12"	0.13"
0.063"	0.09"	0.12"	0.20"	0.31"	0.09"	0.09"	0.15"	0.14"	0.15"
0.071"	0.10"	0.14"	0.27"	0.35"	0.10"	0.10"	0.16"	0.16"	0.18"
0.080"	0.12"	0.16"	0.33"	0.40"	0.12"	0.120"	0.18"	0.18"	0.22"
0.090"	0.13"	0.18"	0.37"	n/a	0.13"	0.13"	0.20"	0.22"	0.25"
0.100"	0.14"	0.20"	0.43"	n/a	0.14"	0.14"	0.25"	0.25"	0.28"
0.125"	0.17"	0.25"	0.55"	n/a	0.15"	0.15"	0.28"	0.31"	0.34"
0.160"	0.25"	0.31"	0.74"	n/a	0.25"	0.25"	0.34"	0.37"	0.44"
0.180"	n/a	n/a	0.87"	n/a	n/a	n/a	n/a	n/a	n/a
0.190"	0.31"	0.38"	n/a	n/a	0.31"	0.31"	0.44"	0.44"	0.63"

5.3.3 Carry out dimpling according to PPS 1.01.

5.3.4 Bend, flare and bead tubing according to PPS 6.01.

5.3.5 Magnetic pulse form tube end fittings according to PPS 1.08 and tubes according to PPS 1.34.

5.3.6 Swage tubes according to PPS 1.06.

5.4 Rework After Forming

5.4.1 Classify and rework surface defects caused by forming according to PPS 27.01.

5.4.2 Shrinking (crimping) flanges in order to straighten a warped part or to remove waviness is acceptable provided that the resulting material is not gouged, scored or reduced in thickness. If crimping, use fibre crimping jaws or stipple-faced steel crimping jaws. Crimp 7075 alloy in the O or W condition only. Clean-up after crimping by hand abrading along the flange using Scotch-Brite pads.

5.5 Fluorescent Penetrant Inspection

5.5.1 Submit formed parts for fluorescent penetrant inspection according to PPS 20.03 in each of the following instances:

- If the engineering drawing specifies a bend radius less than the minimum specified in Table 2 (only required in the bend area).
- After straightening or post-forming rework (only required in the straightened or reworked area).
- On all parts formed and/or straightened in the 'W' condition, if the time/temperature limits of PPS 30.01 have been exceeded.
- On all parts manufactured from 2024 alloy that were formed more than 30 minutes after removal from cold storage.
- On all parts straightened in the naturally or artificially aged condition.
- On all aluminum alloy extruded shapes which receive a joggle operation.

6 Requirements

6.1 Formed parts must conform to the requirements of the engineering drawing.

6.2 Waviness resulting from forming is acceptable if the depth measured from a straight edge laid across two crests to the contained trough does not exceed 1/32". However, if attachment or external appearance is affected, waviness cannot be tolerated.

6.3 Parts with any notching of part edges or cracks are not acceptable. Except for pronounced straight lines caused by faulty stipple jaws, stipple marks caused by crimping are acceptable.

6.4 Evidence of orange peel effect on skins is not acceptable if the external appearance of the part is affected. Minor cases of orange peel must be referred to Bombardier (Toronto Site) MRB or Bombardier (Toronto Site) delegated MRB.

7 Safety Precautions

7.1 The safety precautions specified herein are specific to Bombardier Toronto to meet Canadian Federal and Provincial government environmental, health and safety regulations. It is recommended that other facilities consider these safety precautions; however, suppliers, subcontractors and partners are responsible for ensuring that their own environmental, health and safety precautions satisfy the appropriate local government regulations.

7.2 Observe general shop safety precautions when performing the procedure specified herein.

7.3 The handling of the ASEA press mats may be awkward due to their weight and lack of rigidity. Lift the mats instead of dragging them, as dragging will put more stress to one side of your body. Always use two people to handle the mats. Do not stack mats before lifting them.

8 Personnel Requirements

8.1 This PPS has been categorized as a “Controlled Special Process” by PPS 13.39. Refer to PPS 13.39 for personnel requirements.

9 Formability of Materials

9.1 General

9.1.1 Wrought aluminum alloys are divided into non-heat treatable alloys and heat treatable alloys. Non-heat treatable alloys depend entirely on cold work to obtain their maximum properties whereas heat treatable alloys obtain their full properties only through heat treatment, although they work harden to a limited degree. Refer to Table 3 for a listing of non-heat treatable and heat treatable alloys. Refer to Table 4 for a listing of the stretch formability of various alloys and tempers.

Table 3 - Non-Heat Treatable and Heat Treatable Alloys

Non-Heat Treatable Alloys	Heat Treatable Alloys
1000 series	2000 series
3000 series	6000 series
5000 series	7000 series

Table 4 - Stretch Formability

Alloy	F_{TU} (ksi)	F_{TY} (ksi)	E (%)	Stretchability Rating
7075-W	48	20	19	100
2024-W	46	18	20	98
2024-T3	64	44	18	95
6061-W	35	21	22	90
7075-O	32	14	17	80
2024-O	27	11	19	80
6061-O	18	8	22	75
3003-O	16	6	30	75
7075-T6	76	67	11	10

9.2 Non-Heat Treatable Alloys

9.2.1 Generally, non-heat treatable alloys are lower in strength and higher in ductility than heat treatable alloys, but are not necessarily more formable because some non-heat treatable alloys have a rapid rate of strain hardening (e.g. 5052).

9.2.2 Due to their ductility, the non-heat treatable alloys can be formed quite severely in the full hard temper with very little trouble.

9.2.3 Non-heat treatable alloys in the O condition can be subjected to complex forming operations and first form operations are almost unlimited. However, interstage annealing may become necessary if a part is to be subjected to several severe forming operations.

9.2.4 Non-heat treatable alloys in the strain hardened condition are more difficult to form depending on the degree of hardness (i.e. full-hard tempers H-18, H-28 and H-38 are less ductile than half-hard tempers H-14, H-24 and H-34 which are in turn less ductile than quarter-hard tempers H-12, H-22 and H-32), but are ductile enough for forming operations which do not involve deep drawing.

9.3 Heat Treatable Alloys

9.3.1 Heat treatable alloys, although less ductile than the non-heat treatable alloys, can be subjected to quite severe forming operations in the annealed O condition and to a lesser degree in the solution heat treated W condition.

9.3.2 In the T3, T4 and T6 conditions, heat treatable alloys can be formed satisfactorily provided the bends are simple (e.g., straight flanges).

9.3.3 In general, where heat treatable alloys are to be subjected to a stretching or shrinking action, solution heat treatment according to PPS 30.01 before forming will be necessary. The parts must be formed in the W condition immediately on removal from the quench bath unless parts are refrigerated at this stage in which case forming may delayed according to PPS 30.01. After forming, 7000 series alloys which have undergone a solution heat treatment operation must be artificially age hardened.

9.3.4 Forming in the annealed O condition should be confined to parts where more than one hit is necessary due to the complex shape of the part. In such cases, the last forming operation should be carried out with the material in the solution heat treated W condition.

9.3.5 Forming alloy in the T3 or T4 temper should be restricted to simple bends in thin gauge material up to 0.05" thick, such as convex flanges with little curvature, flanges where shrinkage is eliminated by the incorporation of notches and shallow open angle impressions or bends.

9.3.6 Heavy gauge and intricately shaped heat treatable alloy parts which will require more than one forming operation should be initially formed in the annealed O condition and then solution heat treated before the last forming operation. If the engineering drawing specifies the final temper of T3, this method may not be used.

9.3.7 Refer to Table 5 for the approximate amount of springback in heat treatable alloys of different tempers.

9.3.8 Except when using the diaphragm forming method, only 2004 and 7475 alloys may be used in the superplastic forming process. When forming using the diaphragm forming method, a sheet of non-superplastic alloy is sandwiched between two sheets of superplastic alloy (i.e., 2004 or 7475). Using this method, it may be possible to form non-superplastic alloys.

Table 5 - Springback for Heat Treatable Alloys

Material Condition	Degree of Springback
Annealed - O	2°
Solution Heat Treated - W	5°
T3 or T4	8.5°

10 Forming Equipment

10.1 The appropriate equipment is determined by the alloy, temper, bend radius, material thickness, size, and shape of the part. Many sheet metal parts require only simple bending around one axis to form the complete part. The most commonly used machines for forming such parts are the ASEA press power brake, etc.

10.1.1 The ASEA press is used, with the aid of form blocks and polyurethane forming pads, to simultaneously form various types of flanges, lightening holes, swages, joggles, etc. around flat planes. The maximum forming pressure of the ASEA press is 14,500 psi.

10.1.2 The Niagara press is used with the aid of form blocks and polyurethane forming pads to simultaneously form various types of flanges, swages, joggles, etc. around flat planes. The Niagara press is similar to the rubber press, but on a smaller scale.

10.1.3 The power brake is used for forming the majority of open ended parts such as channels and angles. The power brake can also be used for straight line contour forming if a smooth continuous contour is not mandatory. Joggling of CV and CS sections may also be carried out using the power brake.

10.1.4 The mechanical press is used for forming joggles in extruded sections. Joggling is carried out with special heated or non-heated dies as appropriate.

10.1.5 The Farnham rolls are used for straight line contour forming (e.g., such as leading edge skins).

10.1.6 The Hufford stretch press is used mainly for forming extruded shapes. Reverse curvatures can be accomplished by special pressure blocks and removable die sections located in the main form block. Approximately 6" extra length should be allowed for chucking. Due to the strength requirements of parts formed on this machine the principle alloys that will be used will be heat treatable alloys in the T3 or T4 temper. Where forming is to be severe the part should be in the solution heat treated W condition.

10.1.7 The Buffalo rolls are used for forming single radius curvatures in CV and CS sections of symmetrical cross-sectional area. Straight line flanges can also be formed on this machine.

10.1.8 The wheeling machine should only be used for correction of discrepancies in a contoured part and should not be used for primary forming operations, particularly in clad sheet.

10.1.9 With special tooling, oval shapes can be formed using lathes. Spin forming is accomplished by the application of localized pressure to the outside of a disc rotating at high speed on a lathe as the disc is drawn over a male form block.

10.1.10 The angle bender, or bar folder, is used for forming straight line bends in flat sheet stock.

10.1.11 The Wals roller, or slip roller, is a manually operated, non-precision machine. It is used for forming straight line contours, conical and cylindrical shapes in flat stock.

10.1.12 The rotary swaging machine is used for reducing and tapering of tubing diameters.

10.1.13 Magnetic pulse forming is used to expansion or compression form circular parts for part shaping or mechanical joining (e.g., control rods).

11 Material Limitations

11.1 The following paragraphs detail the tempers, maximum part dimensions, etc. which may be formed on each particular type of forming machine.

11.1.1 Both non-heat treatable and heat treatable alloys, with the exclusion of alloys in the T6 temper, are suitable for forming on the ASEA press depending on the extent and severity of the forming operation. The maximum form block height to be used on the ASEA press is 5". The bed of the ASEA press is 157" long by 43" wide. Material over 0.156" in thickness or in the T6 temper should not be formed on the ASEA press. Heat treatable alloys with shrink or stretch flanges should be formed in the solution heat treated W condition.

11.1.2 The maximum form block height to be used on the Niagara press is 2.5". The bed of the Niagara press is 17" long by 15" wide. Material over 0.100" in thickness or in the T6 temper should not be formed on the Niagara press. Heat treatable alloys with shrink or stretch flanges should be formed in the solution heat treated W condition. Forming of heat treatable alloys in the annealed O condition should be confined to parts requiring more than one forming operation due to their complex shape. In these cases, the last forming operation should be carried out with the material in the W condition.

11.1.3 The maximum material size that can be formed on the power brake is 126" long and 0.375" thick. Materials in the W condition should not be formed on the power brake unless a suitable straightening operation, such as a first form on the rubber press, has been performed. The reason for this is that the parts warp considerably during quenching after heat treatment. Except 2014-T6, 7075-T6 and 7075-T7351 alloys, joggling of CV and CS sections in the T3, T4 or T6 can be carried out at room temperature. 2014-T6, 7075-T6 and 7075-T7351 alloys must be hot joggled according to PPS 1.03.

11.1.4 Forming on the mechanical press should be restricted to joggling. Except 2014-T6, 7075-T6 and 7075-T7351 and 7075-T7351, joggling of material in the T3, T4 or T6 tempers can be carried out at room temperature. 2014-T6, 7075-T6 and 7075-T7351 alloys must be hot joggled according to PPS 1.03.

11.1.5 The Farnham rolls can handle material up to 15 feet in length and up to 0.090" thick. Forming on the Farnham rolls should be restricted to heat treatable alloys in the T3 or T4 temper.

11.1.6 The Hufford stretch press can form parts up to 180" in length. The gripping jaws of the Hufford stretch press will accept most shapes up to a 4" diameter circle. Forming on the Hufford stretch press should be restricted to heat treatable alloys due to the high work hardening effect on non-heat treatable alloys. If forming is to be severe, the parts should be formed in the solution heat treated W condition.

11.1.7 Forming on the Buffalo rolls should be restricted to heat treatable alloys in the T3 or T4 temper.

11.1.8 The Wals roller, or slip roller, can form flat stock up to 6 feet in length and 0.63" thick.

11.1.9 Spinning should be performed in the annealed O condition. Interstage annealing may be necessary for most alloys.

11.1.10 For Superplastic forming, refer to Table 6 for the recommended forming method for the part based on the aspect ratio of the formed part. The recommended minimum plan, section and flange radii are shown in Table 7. The average final part thickness will be related to the final surface area of the component as follows:

$$t = TF \times T \times PA/A$$

where: t is the average final thickness
TF is the thinning factor (male TF = 1.2, female TF = 1.0 and drape TF = 1.1)
T is the starting thickness
PA is the plan area of the component (i.e. length x width)
A is the total area of the component (includes ends, sides and top)

Table 6 - Recommended Superplastic Forming Method

Aspect Ratio (see Figure 1)		Forming Method (Note 1)
Unclad	**Clad**	
up to 0.25	up to 0.2	drape
0.25 - 0.35	0.2 - 0.3	female
0.35 - 0.5	0.3 - 0.45	male

Note 1. When design and performance criteria require the properties of common sheet aluminum alloys, the diaphragm forming method must be used.

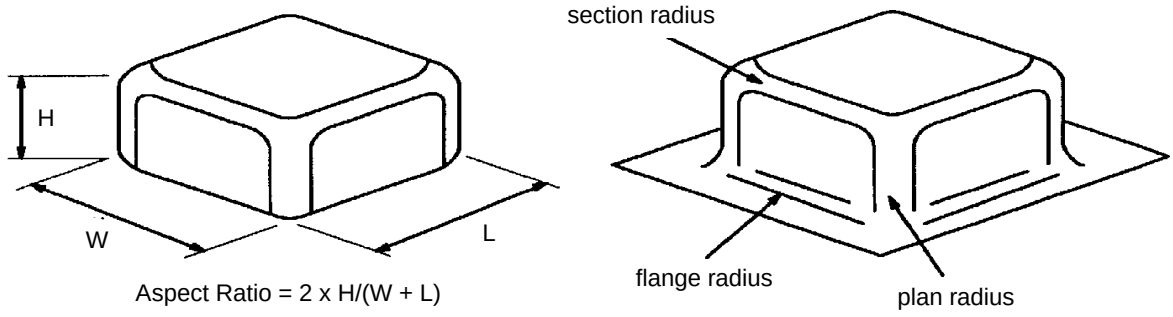

Figure 1 - General Description of a Superplastic Formed Part

Table 7 - Recommended Minimum Radii for Superplastic Forming

Forming Method	Aspect Ratio	Plan Radius	Section Radius	Flange Radius
male or drape	0.4 - 0.5	15T	7T	4T
	0.3 - 0.4	12T	6T	5T
	0.2 - 0.3	10T	5T	5T
	0.1 - 0.2	7.5T	4T	6T
	0 - 0.1	5T	3T	6T
female	0.2 - 0.35	13T	10T	5T
	0.1 - 0.2	9T	7T	4T
	0 - 0.1	7T	5T	3T

Notes: 1. T = starting thickness
2. Refer to Figure 1 for a description of aspect ratio, plan radius, section radius and flange radius.