

PhD Proposal Writeup

A realtime and parallel look-ahead control and feedrate compensation strategy for CNC reference-pulse interpolation.

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7	Type of Study	Research
8	Mode of Study	Full Time
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13	Document Date	June 15, 2023
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Reference: **Draft-44-Report-Latex-PhD-Proposal-WRY.tex**
Date: **June 15, 2023**
Version: **Draft-44**

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1 Simulation Results

1.1 The Parametric Equations

The ten(10) 2D parametric curves covered in this work are:

1. Teardrop
2. Butterfly
3. Ellipse
4. Skewed-Astroid
5. Circle
6. AstEpi = Astroid + Epicycloid combination
7. Snailshell
8. SnaHyp = Snailshell + Hypotrochoid combination
9. Ribbon-10L
10. Ribbon-100l = 10 times scaleup of Ribbon-10L

The parametric equations describing each of the curves $x(u)$, and $y(u)$ are provided in the next table. The independent parameter u is limited to

$$u \in [0.0, 1.0]$$

The curves were selected based on their different characteristics like closed loop curves, open ended curves, symmetric or non-symmetric about the x-axis and y-axis, and having concave or convex turns. The x and y dimensions (sizes) vary among the different curves.

The main objective of the selection criteria is to ensure that the interpolation algorithm for the parametric curve succeeds and does not break in all cases.

The results for the feedrates in machining the ten(10) curves show continuity, smoothness, with no abrupt jumps as the CNC machine traverse the entire curve from the start ($u = 0.0$) until the end ($u = 1.0$).

No. 1 - Teardrop parametric curve

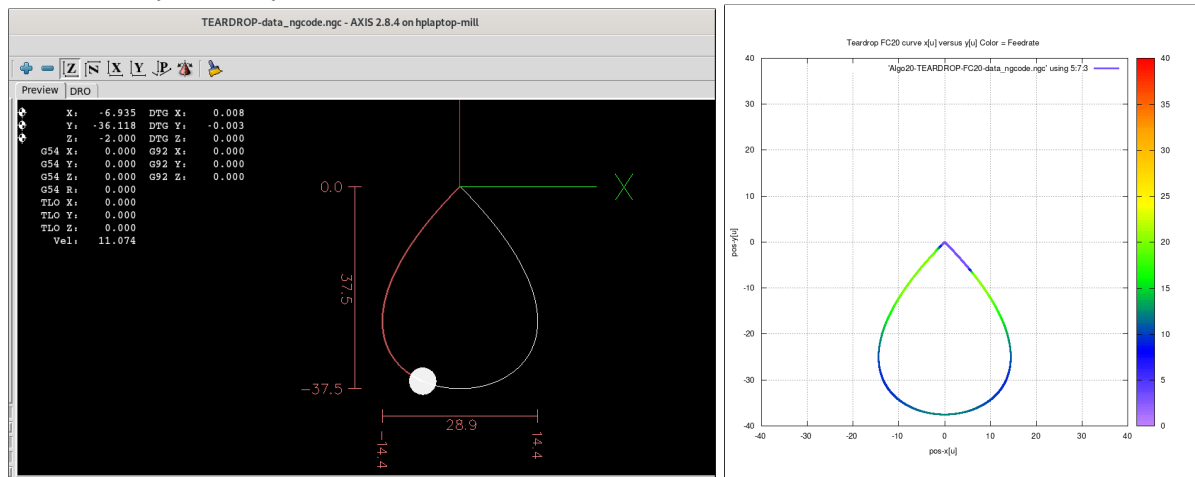
$$\begin{aligned}x(u) &= -150u + 450u^2 - 300u^3 \\y(u) &= -150u + 150u^2 \\u &\in [0.0, 1.0]\end{aligned}$$

Closed loop

Overall Single loop

Reflection x-axis: non-symmetrical

Reflection y-axis: symmetrical

**No. 2 - Butterfly parametric curve**

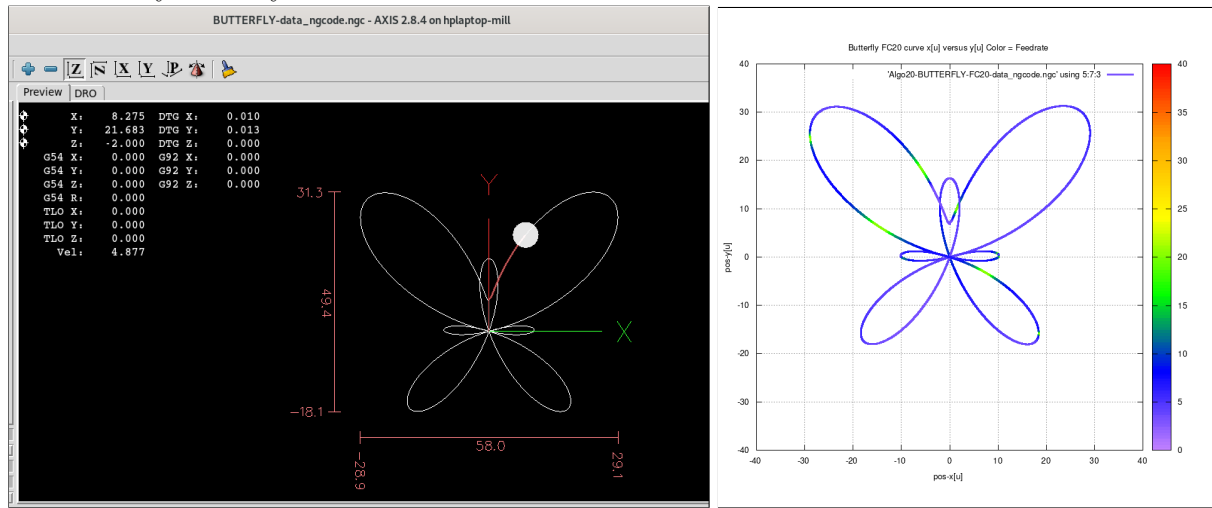
$$\begin{aligned}x(u) &= \sin(2\pi u) [e^{\cos(2\pi u)} - 2\cos(8\pi u) - (\sin(2\pi u/12))^5] \\y(u) &= \cos(2\pi u) [e^{\cos(2\pi u)} - 2\cos(8\pi u) - (\sin(2\pi u/12))^5] \\u &\in [0.0, 1.0]\end{aligned}$$

Closed loop

Overall Multiple loops

Reflection x-axis: non-symmetrical

Reflection y-axis: symmetrical



No. 3 - Ellipse parametric curve

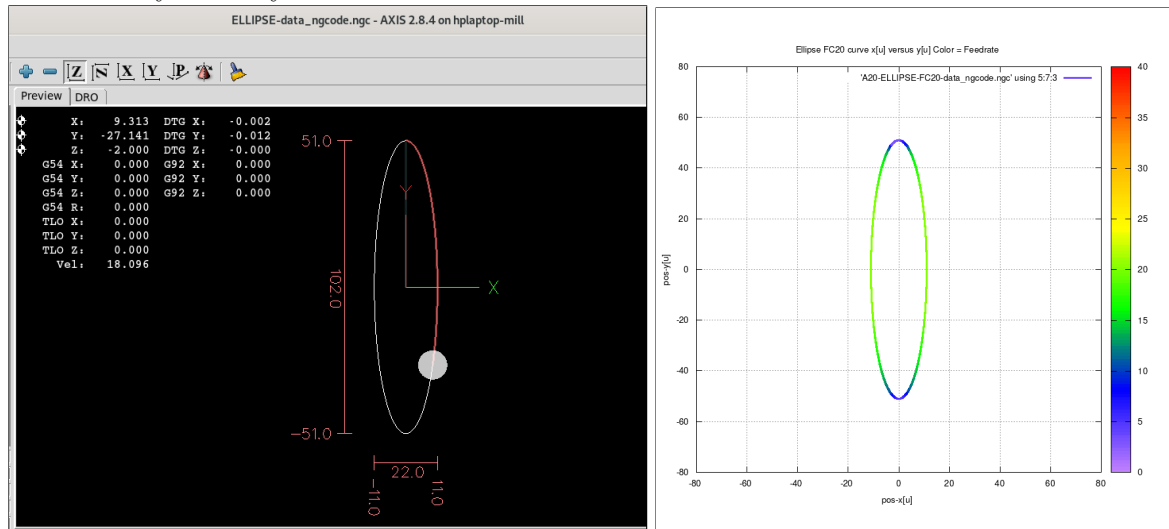
$$\begin{aligned}x(u) &= 11 \sin(2\pi u) \\y(u) &= 51 \cos(2\pi u) \\u &\in [0.0, 1.0]\end{aligned}$$

Closed loop

Overall Single loop, smooth convex curves

Reflection x-axis: symmetrical

Reflection y-axis: symmetrical

**No. 4 - Skewed-Astroid parametric curve**

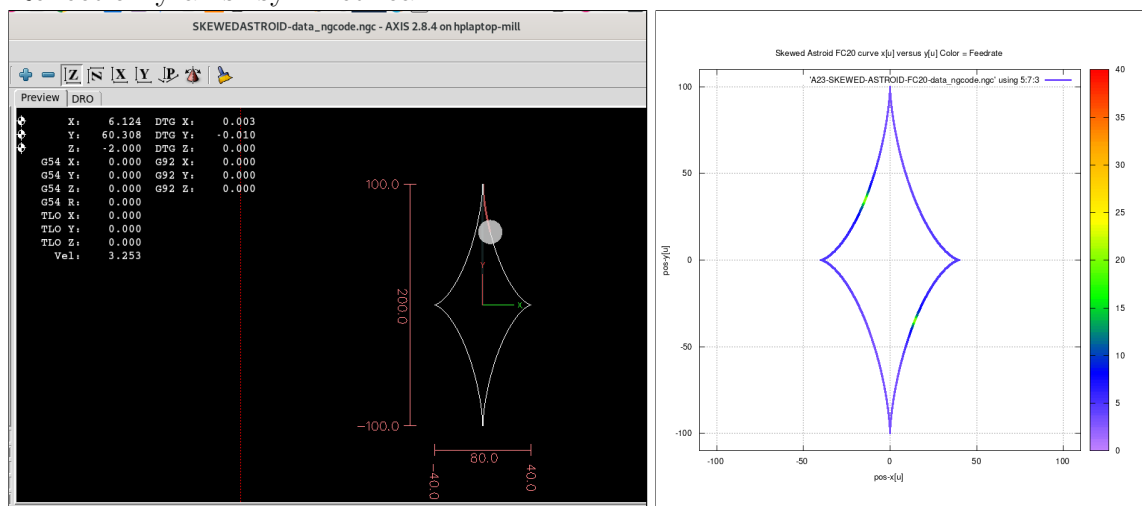
$$\begin{aligned}x(u) &= 40[\sin(2\pi u)]^3 \\y(u) &= 100[\cos(2\pi u)]^3 \\u &\in [0.0, 1.0]\end{aligned}$$

Closed loop

Overall Single loop, 4 cusps and 4 concave curves

Reflection x-axis: symmetrical

Reflection y-axis: symmetrical



No. 5 - Circle parametric curve

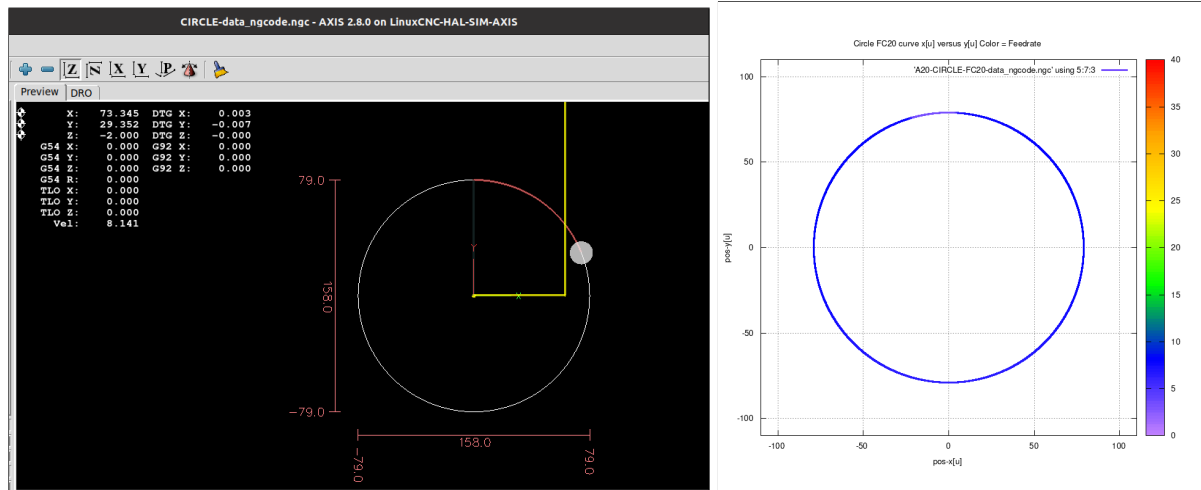
$$\begin{aligned}x(u) &= 79 \sin(2\pi u) \\y(u) &= 79 \cos(2\pi u) \\u &\in [0.0, 1.0]\end{aligned}$$

Closed loop

Overall Single loop, smooth convex curves

Reflection x-axis: symmetrical

Reflection y-axis: symmetrical



No. 6 - AstEpi = Sum of (Astroid + Epicycloid) parametric curves

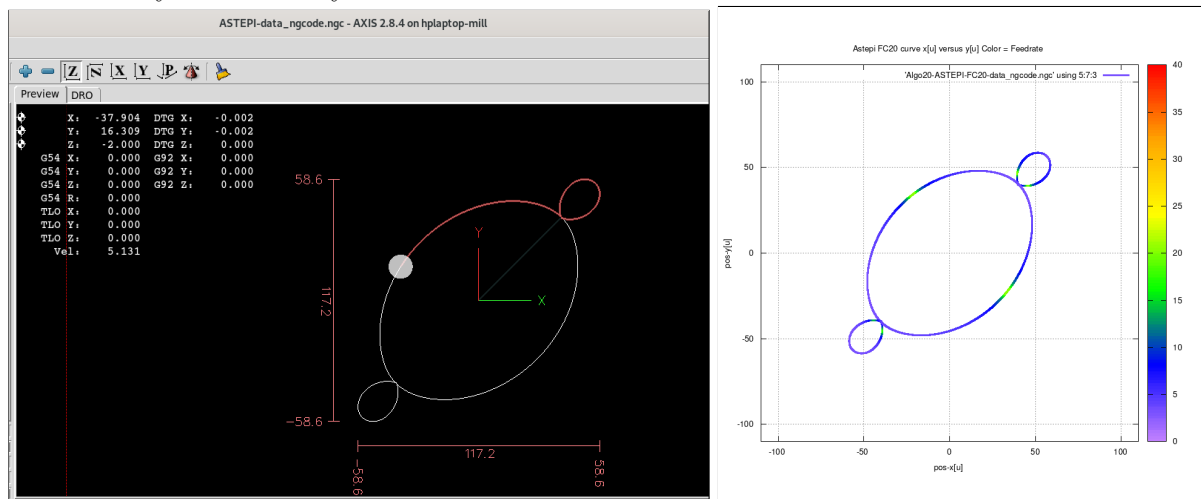
$$\begin{aligned}tiny &= 1.0 \times 10^{-10} \\x(u) &= 40[\sin(2\pi u)]^3 + 50 \cos(2\pi u + tiny) - 10 \cos(10\pi u - tiny) \\y(u) &= 40[\cos(2\pi u)]^3 + 50 \sin(2\pi u + tiny) - 10 \sin(10\pi u - tiny) \\u &\in [0.0, 1.0]\end{aligned}$$

Closed loop

Overall Three loops, all convex curves

Reflection x-axis: non-symmetrical

Reflection y-axis: non-symmetrical



No. 7 - Snailshell parametric curve

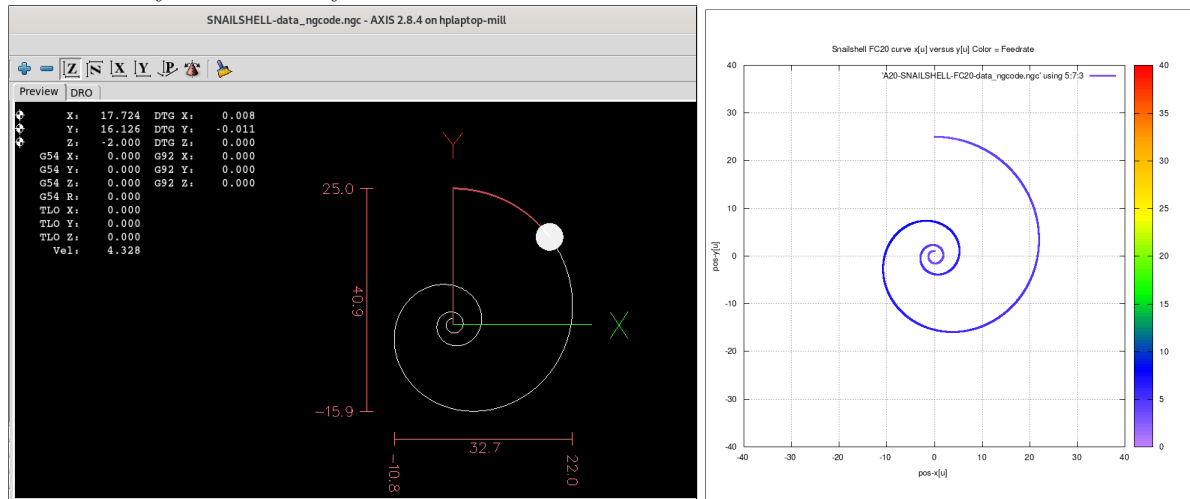
$$\begin{aligned}x(u) &= 79 \sin(2\pi u) \\y(u) &= 79 \cos(2\pi u) \\u &\in [0.0, 1.0]\end{aligned}$$

Open ended curve

Overall No loop, smooth and continuous convex curves

Reflection x-axis: non-symmetrical

Reflection y-axis: non-symmetrical

**No. 8 - SnaHyp = Sum of (Snailshell + Hypotrochoid) parametric curves**

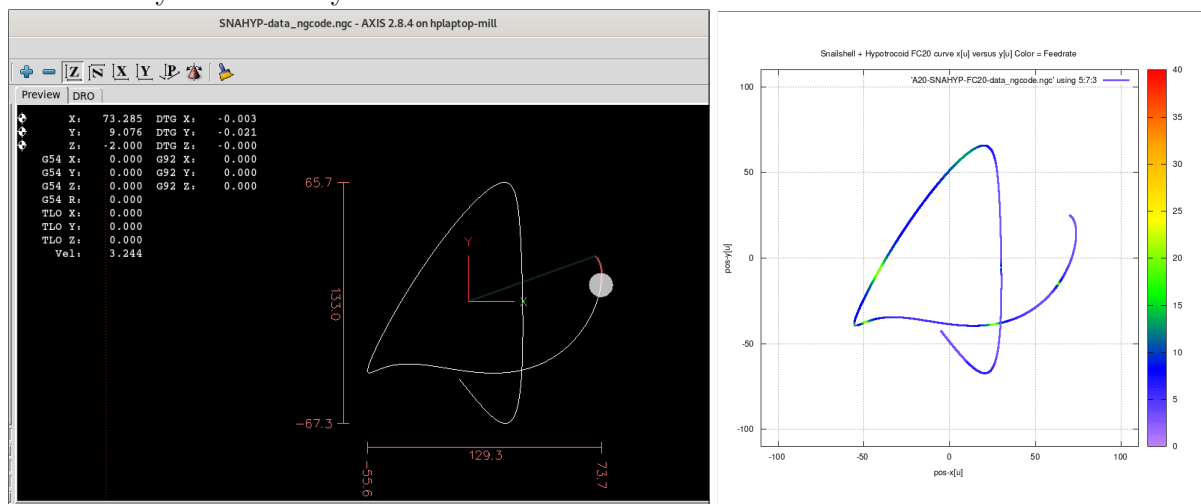
$$\begin{aligned}tiny &= 1.0 \times 10^{-10} \\x(u) &= 40[\sin(2\pi u)]^3 + 50 \cos(2\pi u + tiny) - 10 \cos(10\pi u - tiny) \\y(u) &= 40[\cos(2\pi u)]^3 + 50 \sin(2\pi u + tiny) - 10 \sin(10\pi u - tiny) \\u &\in [0.0, 1.0]\end{aligned}$$

Open ended curve

Overall 1 loop, except for 1 concave curve, the rest are convex curves

Reflection x-axis: non-symmetrical

Reflection y-axis: non-symmetrical



No. 9 - Ribbon-10L parametric curve

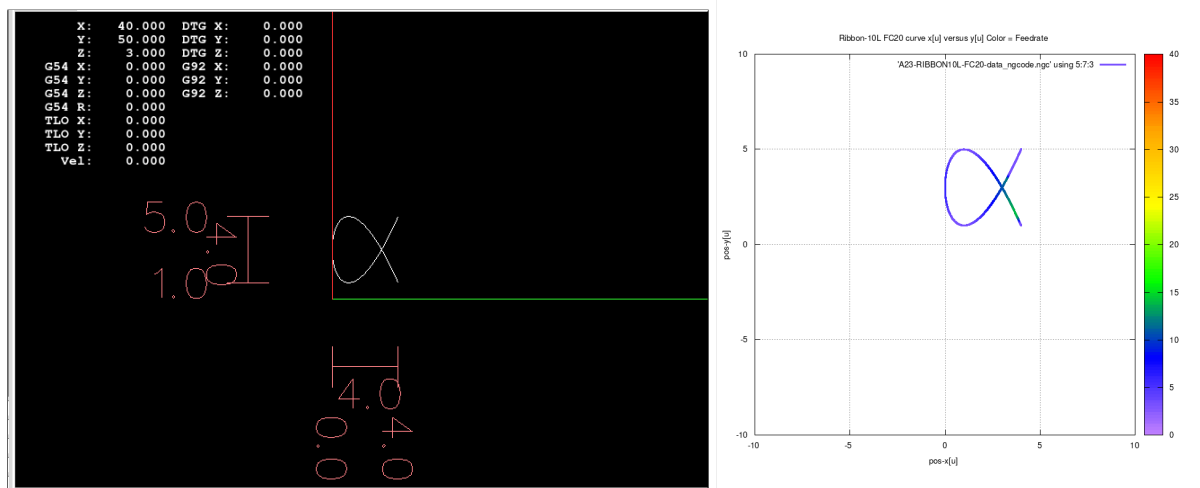
$$\begin{aligned}x(u) &= 79 \sin(2\pi u) \\y(u) &= 79 \cos(2\pi u) \\u &\in [0.0, 1.0]\end{aligned}$$

Open ended curve

Overall Single loop, smooth convex curves

Reflection x-axis: non-symmetrical

Reflection y-axis: non-symmetrical

**No. 10 - Ribbon-100L parametric curve**

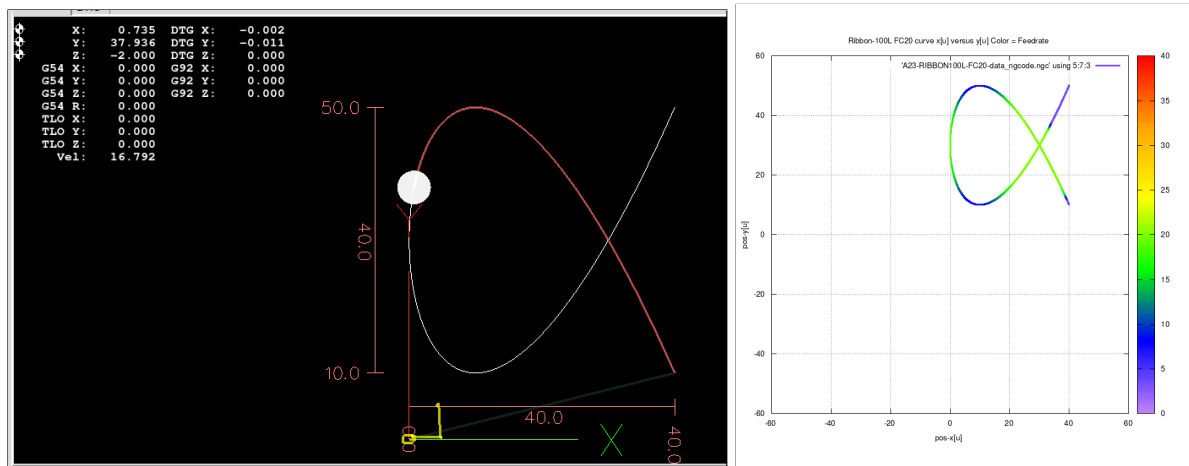
$$\begin{aligned}tiny &= 1.0 \times 10^{-10} \\x(u) &= 40[\sin(2\pi u)]^3 + 50 \cos(2\pi u + tiny) - 10 \cos(10\pi u - tiny) \\y(u) &= 40[\cos(2\pi u)]^3 + 50 \sin(2\pi u + tiny) - 10 \sin(10\pi u - tiny) \\u &\in [0.0, 1.0]\end{aligned}$$

Open ended curve (10 times larger than RIBBON-10L)

Overall Single loop, smooth convex curves

Reflection x-axis: non-symmetrical

Reflection y-axis: non-symmetrical



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Report CNC Parametric Curve Interpolation and Trajectory Tracking
Part 1 of 5 Teardrop and Butterfly (x-y) parametric curves

ITEM	DESCRIPTION	TEARDROP CURVE					BUTTERFLY CURVE				
		FC10	FC20	FC25	FC30	FC40	FC10	FC20	FC25	FC30	FC40
1	Run user feedrate command (mm/s)										
2	Total interpolated u-points	10261	7599	7385	7347	7347	35656	18029	14577	12343	9732
3	Parameter completion (reached u-end)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Pushdown epsilon eps(u) algorithm										
4	Count before pushdown, eps(u) is below (1E-6)	8498	1427	527	0	0	35465	17421	13602	11010	7256
5	Count pushdown points, eps(u) to below (1E-6)	1763	6172	6858	7347	7347	191	608	975	1333	2476
	Epsilon eps(u) chord error										
6	Count eps(u) above (1E-6)	0	0	0	0	0	0	0	0	0	0
7	Count eps(u) in (1E-7, 1E-6)	10261	7599	7385	7347	7347	2995	12494	13794	12343	9732
8	Count eps(u) in (1E-8, 1E-7)	0	0	0	0	0	32661	5535	783	0	0
9	Count eps(u) in (1E-9, 1E-8)	0	0	0	0	0	0	0	0	0	0
10	Count eps(u) in (1E-10, 1E-9)	0	0	0	0	0	0	0	0	0	0
11	Count eps(u) below (1E-10)	0	0	0	0	0	0	0	0	0	0
	Count interpolated u-points										
12	Count rising S curve u-points	960	480	389	370	370	1323	693	575	500	418
13	Count frate is lower than fratelimit	4734	4342	4260	4202	4049	17751	8968	7255	6129	4772
14	Count frate is equal to fratelimit	0	0	0	0	0	0	0	0	0	0
15	Count frate is higher than fratelimit	3608	2298	2348	2406	2559	15254	7673	6171	5213	4124
16	Count falling S curve u-points	959	479	388	369	369	1328	695	576	501	418
	Count u-points histogram (G01 codes)										
17	Count u-points [0.00 <= u < 0.10]	1734	875	768	748	748	3463	1763	1431	1214	952
18	Count u-points [0.10 <= u < 0.20]	1120	791	791	791	791	4332	2167	1733	1444	1112
19	Count u-points [0.20 <= u < 0.30]	809	794	794	794	794	2983	1554	1287	1117	927
20	Count u-points [0.30 <= u < 0.40]	726	710	710	711	711	3220	1611	1293	1098	877
21	Count u-points [0.40 <= u < 0.50]	741	629	629	629	629	3832	1920	1545	1299	998
22	Count u-points [0.50 <= u < 0.60]	742	629	629	628	629	3829	1919	1544	1298	997
23	Count u-points [0.60 <= u < 0.70]	726	710	711	711	711	3222	1612	1294	1098	878
24	Count u-points [0.70 <= u < 0.80]	809	794	793	794	793	2981	1553	1286	1117	926
25	Count u-points [0.80 <= u < 0.90]	1120	791	791	791	792	4323	2162	1730	1441	1110
26	Count u-points [0.90 <= u <= 1.00]	1734	876	769	750	749	3471	1768	1434	1217	955
27	Check Total u-points	10261	7599	7385	7347	7347	35656	18029	14577	12343	9732
	Performance										
28	Total curve error (sum of epsilon(u))	0.005809	0.007141	0.007301	0.007337	0.007335	0.001939	0.003534	0.004231	0.004847	0.005851
29	Total dist traversed (sum of chord lengths)	101.8357	101.8419	101.8348	101.8596	101.8356	356.0747	356.0737	356.0723	356.0728	356.0732
30	Percentage (Tot curve error / Tot dist traversed)	0.005704	0.007012	0.00717	0.007203	0.007203	0.000545	0.000993	0.001188	0.001361	0.001643

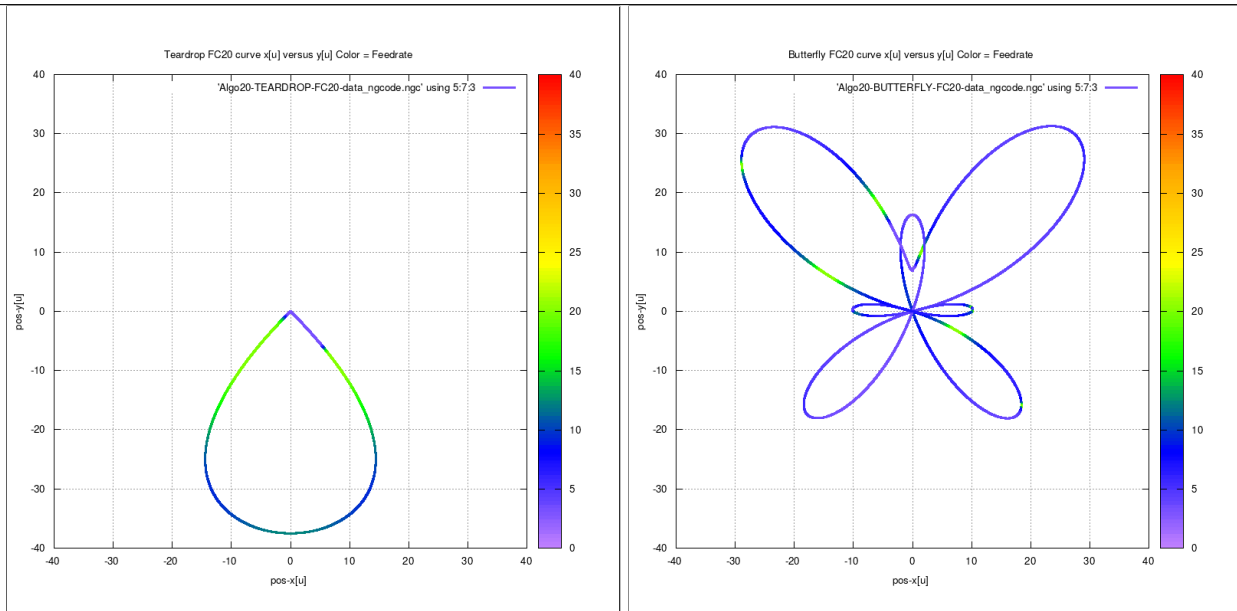


Figure 1.1: Teardrop and Butterfly run data summary

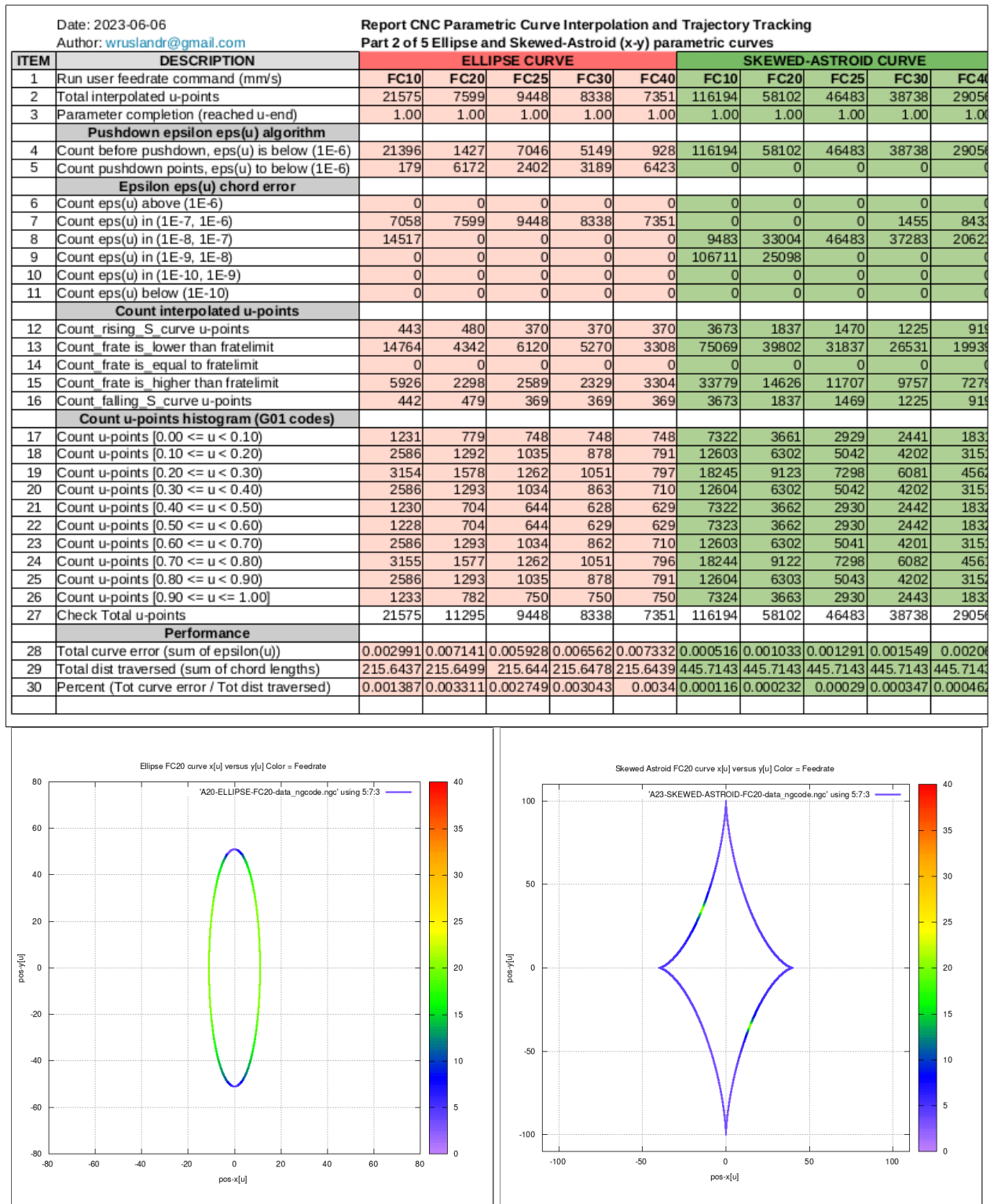


Figure 1.2: Ellipse and Skewed-Astroid run data summary

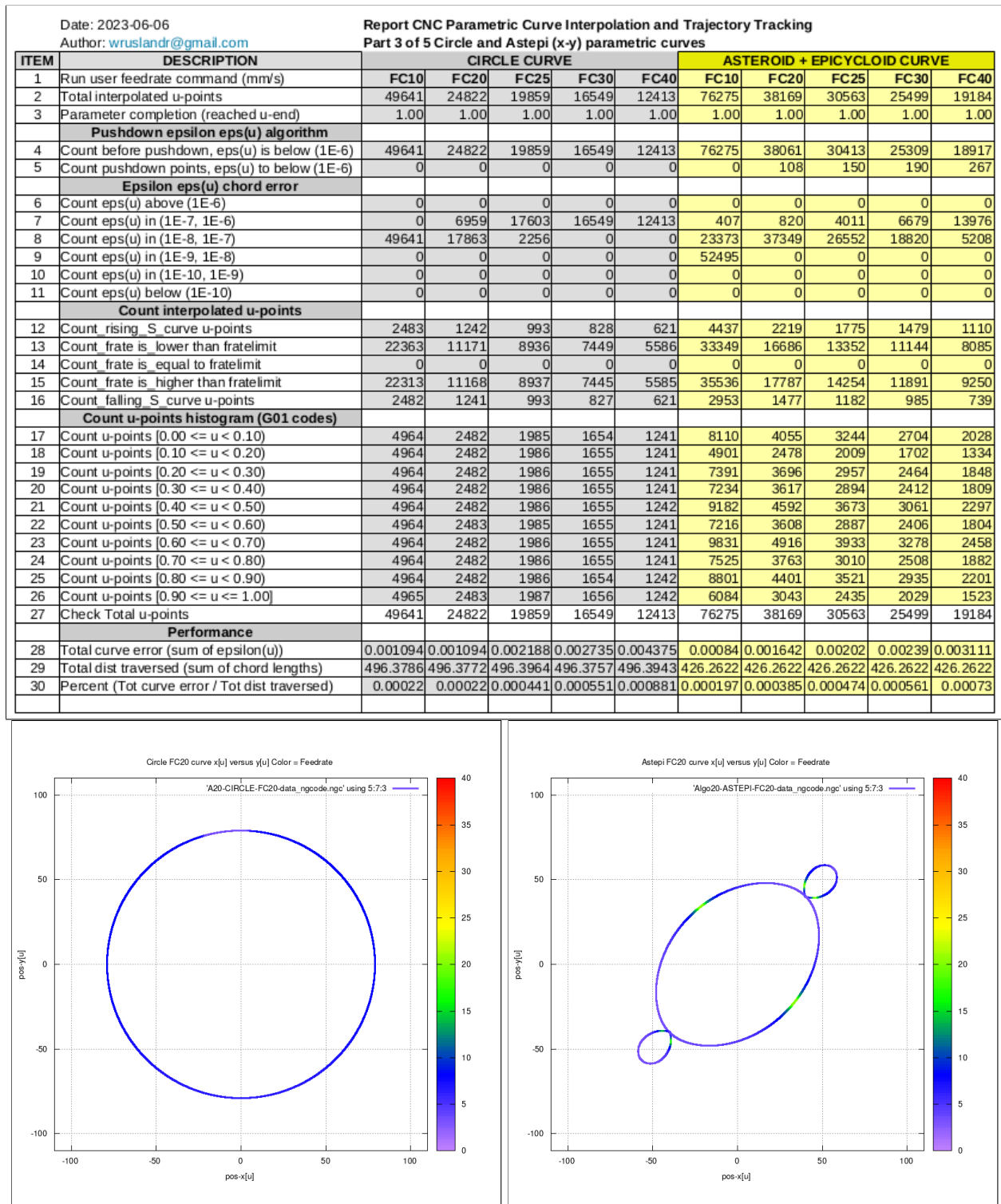


Figure 1.3: Circle and AstEpi run data summary

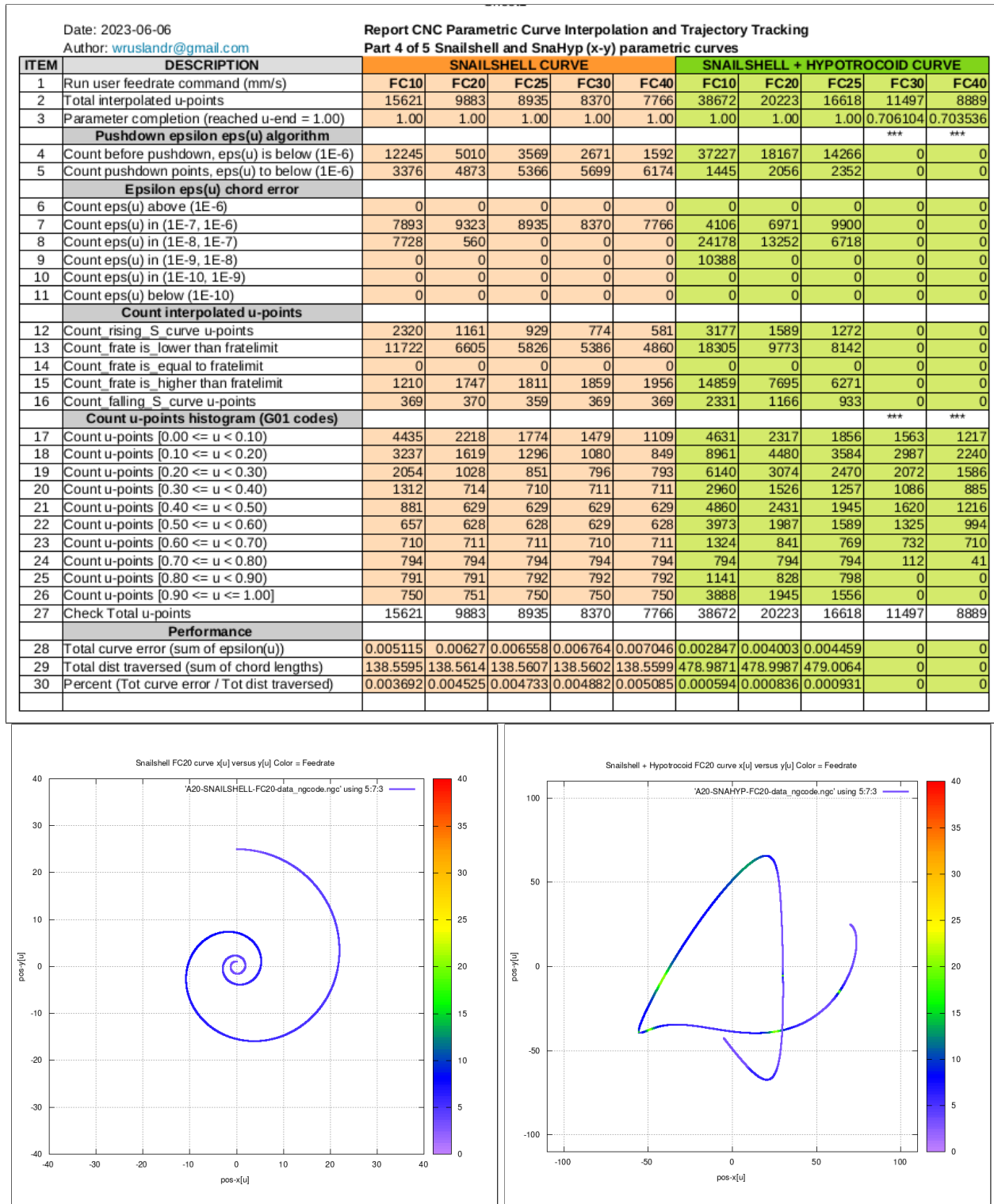


Figure 1.4: Snailshell and SnaHyp run data summary

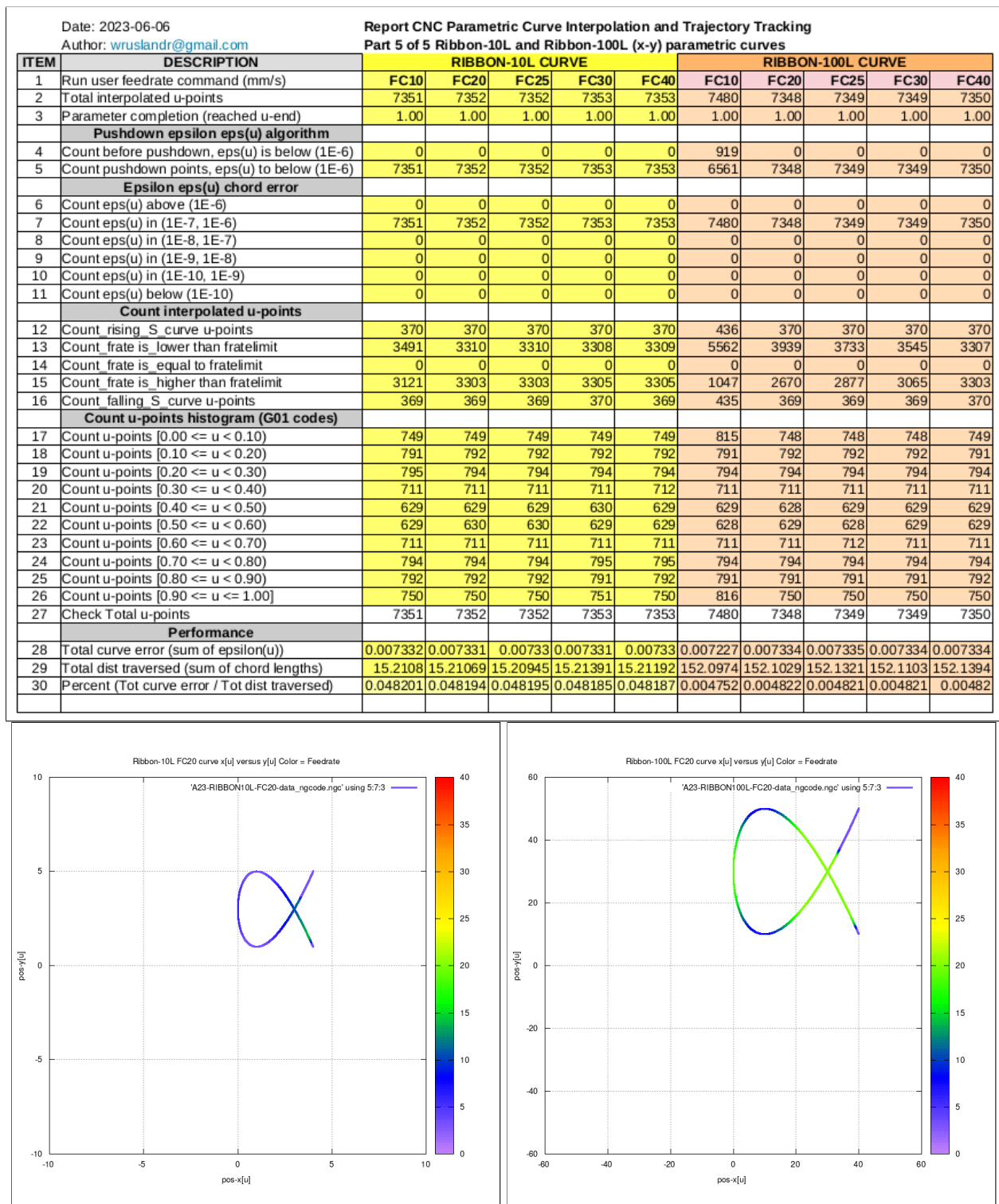


Figure 1.5: Ribbon-10L and Ribbon-100L run data summary