AugerBot Calculations

```
Quit
```

Trial 1: 9/19 - 9/26

Modified Francisco Calculations : 10/18 (Do not use!)

Plotting Fx to find U which Balances Forces: 11/1

Plotting Fx to find U which Balances Forces 2 : 11/9

Inside Equation for Thrust: 11/16

Backtracking: 11/27

Francisco' s with Chen' s Coefficients: 11/30 (CORRECT ONES)

```
Quit;
```

Francisco With Chen' s Coefficients

In[1]:=
```
(*Parameters from paper*)
r = 5/1000; w = 10.4; n = 3.5;

(*LP poppy Fourier coefficients*)
A00 = 0.051; A10 = 0.047; B11 = 0.053; B01 = 0.083;
Bn11 = 0.020; C11 = -0.026; C01 = 0.057; Cn11 = 0; D10 = 0.025;
```

In[3]:=
```
β = (Pi/2) - ϕ; (*ϕ is symbolic, radians*)
αz = Bn11 * Sin[2 * Pi * (-β/Pi)] + A00 * Cos[2 * Pi * 0] +
   B01 * Sin[2 * Pi * 0] + A10 * Cos[2 * Pi * (β/Pi)] + B11 * Sin[2 * Pi * (β/Pi)];
(*Vertical stress per unit depth, N/m^3*)
αx = Cn11 * Cos[2 * Pi * (-β/Pi)] + C01 * Cos[2 * Pi * 0] +
   D10 * Sin[2 * Pi * (β/Pi)] + C11 * Cos[2 * Pi * (β/Pi)];
(*Horizontal stress per unit depth, N/m^3*)

(*Friction coefficients, expressed in terms of ϕ*)
d = 0.05;(*Depth robot buried, 50mm*)
Cn = αx * d; (*N/m^2*)
Ct = αz * d;

Cn /. ϕ → 0
Ct /. ϕ → 0
```

Out[9]= 0.00415

Out[10]= 0.0002

In[11]:=
```
(*Eq 2 - 10/21/17 | Parametrized f Integrated only wrt dθ*)
FranChen[u_] := (2 * Pi * n * r / Cos[ϕ]) *
   ((Cn - Ct) * r * w * Sin[ϕ] * Cos[ϕ] - u * (Ct * Sin[ϕ]^2 + Cn * Cos[ϕ]^2)) /
    Sqrt[u^2 + (r * w)^2];
```

Calculating U/Rw when Fx = 0 for Many ϕ Cases

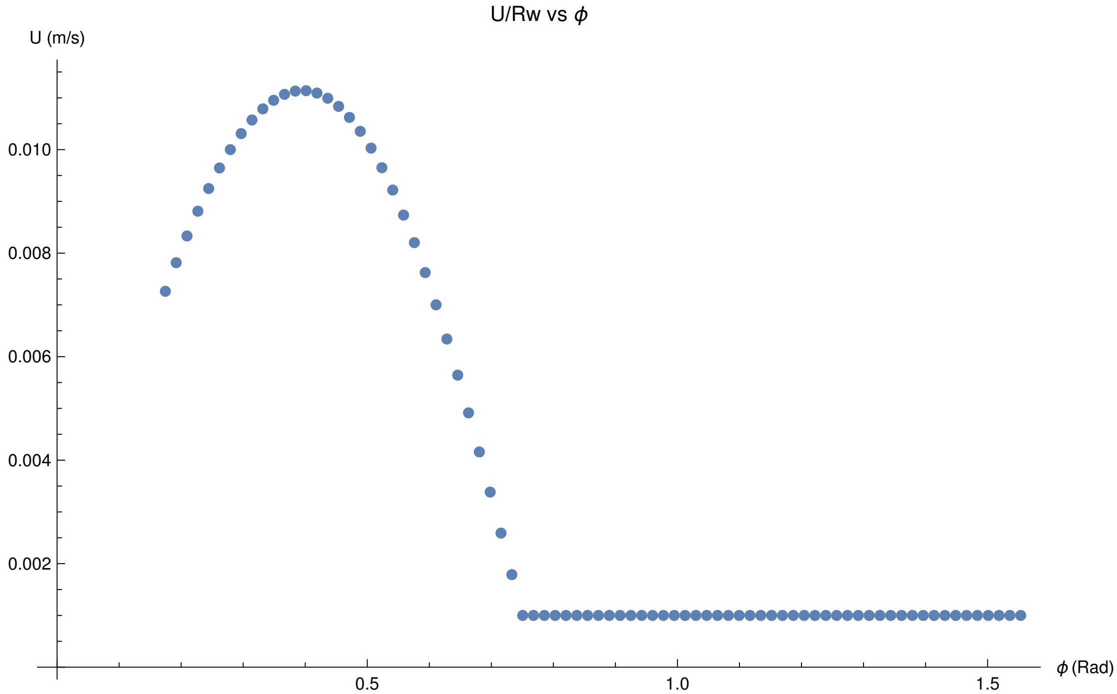
In[12]:=
```
ϕ = 10 * Pi/180 // N; (*Local inclination, radians*)
ϕstore = {};
ustore = {};
Fstore = {};
FMaxstore = {}; (*FxIn when u = 0.001*)
```

In[17]:=
```
(*Finding U intercepts*)
While[ϕ < 90 * Pi / 180,
 (*Print statements*)
 (*Print["Let ϕ = ",ϕ*180/Pi, " deg"];*)
 (*Print@
   Plot[{FranChen[u],0},{u,0,0.2}, PlotLabel→"Inner Fx vs. Helix Velocity U/Rw",
    AxesLabel→{"U (m/s)","Fx (N/m^2)"}, PlotRange→All];*)

 (*Finding U intercept: Newton-Raphson Method*)
 guess = 0.001; (*Reset initial guess*)
 grad = D[FranChen[u], u];
 While[FranChen[guess] > 10^-6, (*Keep iterating until FxIn ≃ 0*)
  gradEval = grad /. u → guess; (*Find FxIn'(guess)*)
  guess = guess - FranChen[guess] / gradEval (*u_{i+1} = u_i - FxIn(u_i)/FxIn'(u_i)*)
 ];
 uint = guess; (*U/Rw intercept found*)

 (*Storing data in arrays*)
 ϕstore = Join[ϕstore, {ϕ}]; (*Storing ϕ in Radians*)
 FMaxstore = Join[FMaxstore, {FranChen[10^-3]}]; (*FxIn(0.001)*)
 ustore = Join[ustore, {uint}]; (*U found when FxIn < 10^-6*)
 Fstore = Join[Fstore, {FranChen[uint]}]; (*FxIn val at u-intercept*)

 ϕ = ϕ + (1 * Pi / 180) (*Increment by 1 deg*)
]
```

Plotting Francisco - Chen Results

In[18]:=
```
ϕFCcol = {ϕstore}ᵀ; uFCcol = {ustore}ᵀ;

(*Helix Translation Speed vs. Local Incline Angle ϕ*)
dataPlot = Join[ϕFCcol, uFCcol, 2];
ListPlot[dataPlot, PlotLabel → "U/Rw vs ϕ",
 AxesLabel → {"ϕ (Rad)", "U (m/s)"}, ImageSize → Large]
```

Out[20]=



Using Chen's Fourier coefficients does result in a maximum speed!!! Only phi values between 0 and 45 ° produce net forward thrust results!

Testing Auger Model with Correct Chen Coefficients

Parameters

For Helix

In[1]:=
```
(*Current param: R = 1.8cm, n = 3.5*)
R = 0.018; (*Screw radius, m*)
n = 3.5; (*Number of helix turns*)
```

For Material

In[3]:=
```
(*LP poppy Fourier coefficients*)
A00 = 0.051; A10 = 0.047; B11 = 0.053; B01 = 0.083;
Bn11 = 0.020; C11 = -0.026; C01 = 0.057; Cn11 = 0; D10 = 0.025;

β = (Pi / 2) - ϕ; (*ϕ is symbolic, radians*)
αz = Bn11 * Sin[2 * Pi * (-β / Pi)] + A00 * Cos[2 * Pi * 0] +
   B01 * Sin[2 * Pi * 0] + A10 * Cos[2 * Pi * (β / Pi)] + B11 * Sin[2 * Pi * (β / Pi)];
(*Vertical stress per unit depth, N/m^3*)
αx = Cn11 * Cos[2 * Pi * (-β / Pi)] + C01 * Cos[2 * Pi * 0] +
   D10 * Sin[2 * Pi * (β / Pi)] + C11 * Cos[2 * Pi * (β / Pi)];
(*Horizontal stress per unit depth, N/m^3*)

d = 0.05;(*Depth robot buried, m*)

(*Friction coefficients, expressed in terms of ϕ*)
Cn = αx * d; (*N/m^2*)
Ct = αz * d;
```

For Motor

In[10]:=
```
w = 2 * 1000 * (2 * Pi) / 3584;(*Angular velocity with 12V source, rad/s*)
```

- (2 ticks/ms)*(1000 ms/s)*(2*Pi rad/rev)*(1 rev/3584 ticks)

Horizontal Thrust Inner Equation

In[11]:=
```
FxIn[U_] := (2 * Pi * n / Cos[ϕ]) *
    (((Cn - Ct) * w * Sin[ϕ] * Cos[ϕ]) * (((R / (2 * w^2)) * Sqrt[(R * w)^2 + U^2]) +
         ((U^2 / (2 * w^3)) * (Log[U] - Log[R * w + Sqrt[(R * w)^2 + U^2]]))) -
      (U * (Ct * Sin[ϕ]^2 + Cn * Cos[ϕ]^2) * (Sqrt[(R * w)^2 + U^2] - U) / w^2));
```

ϕ input must be in radians

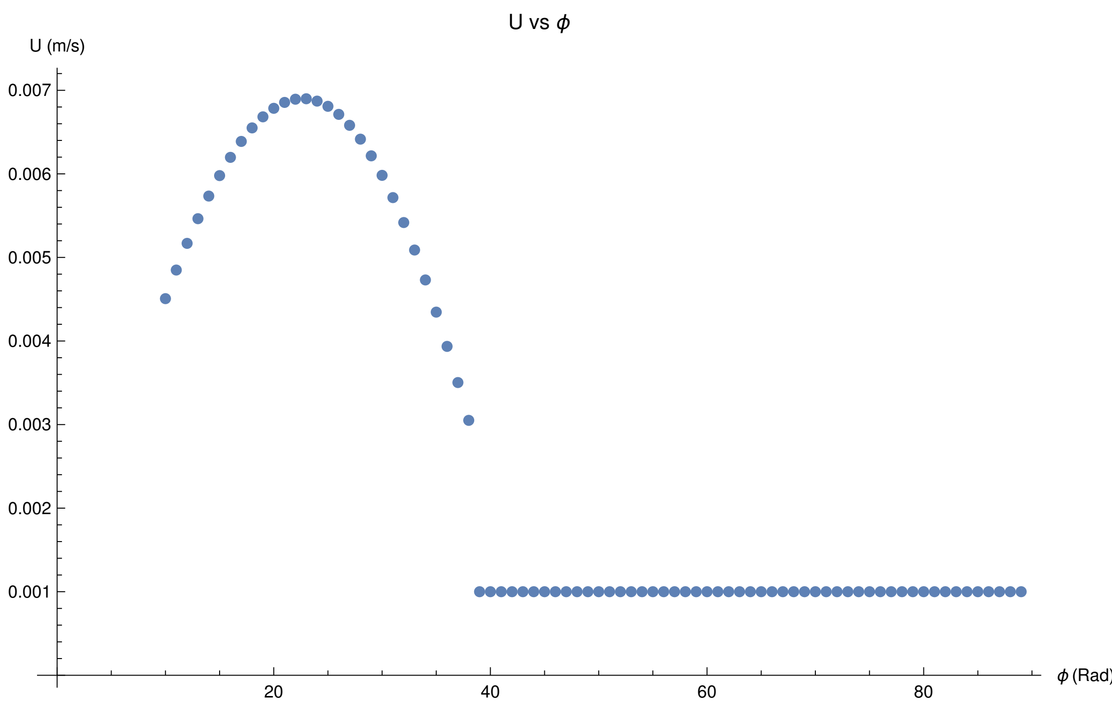
Calculating U/Rw when Fx = 0 for Many ϕ Cases

In[12]:=
```
ϕ = 10 * Pi / 180 // N; (*Local inclination, radians*)
ϕstore = {};
Ustore = {};
Fstore = {};
FMaxstore = {}; (*FxIn when u = 0.001*)
```

```
In[17]:= While[ϕ < 90 * Pi / 180,
  (*Print statements*)
  (*Print["Let ϕ = ",ϕ*180/Pi, " deg"];*)
  (*Print@Plot[{FxIn[U],0},{U,0,0.1}, PlotLabel→"Inner Fx vs. Helix Velocity U/Rw",
     AxesLabel→{"U (m/s)","Fx (N/m^2)"}, PlotRange→All];*)

  (*Finding U intercept: Newton-Raphson Method*)
  guess = 0.001; (*Reset initial guess*)
  grad = D[FxIn[U], U];
  While[FxIn[guess] > 10^-6, (*Keep iterating until FxIn ≃ 0*)
   gradEval = grad /. U → guess; (*Find FxIn'(guess)*)
   guess = guess - FxIn[guess] / gradEval (*u_{i+1} = u_i - FxIn(u_i)/FxIn'(u_i)*)
  ];
  Uint = guess; (*U intercept found*)

  (*Storing data in arrays*)
  ϕstore = Join[ϕstore, {ϕ}]; (*Storing ϕ in Radians*)
  FMaxstore = Join[FMaxstore, {FxIn[10^-3]}]; (*FxIn(0.001)*)
  Ustore = Join[Ustore, {Uint}]; (*U found when FxIn < 10^-6*)
  Fstore = Join[Fstore, {FxIn[Uint]}]; (*FxIn val at U-intercept*)

  ϕ = ϕ + (1 * Pi / 180) (*Increment by 1 deg*)
 ]
```

Analysis

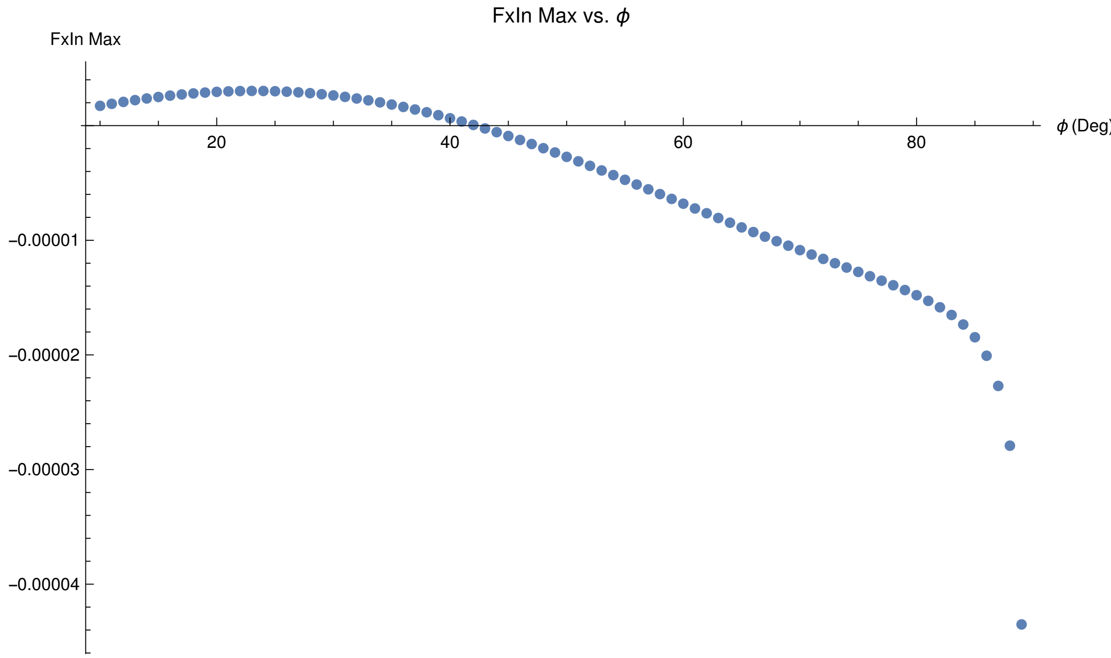
In[18]:=
```
ϕcol = {ϕstore}ᵀ;
Ucol = {Ustore}ᵀ;
Fcol = {Fstore}ᵀ;
Fmaxcol = {FMaxstore}ᵀ;

(*Helix Translation Speed vs. Local Incline Angle ϕ*)
dataPlot = Join[ϕcol * 180 / Pi, Ucol, 2];
ListPlot[dataPlot, PlotLabel → "U vs ϕ",
 AxesLabel → {"ϕ (Rad)", "U (m/s)"}, ImageSize → Large]
```

Out[20]=


With Chen's coefficients, the dimensional Fx equation does yield a U maximum speed :) Same deal with Francisco's model, where net forward thrust only exists for $0 < \phi < 40°$

In[21]:=
```
(*FxIn Max vs. Local Incline Angle ϕ*)
dataMax = Join[ϕcol * 180 / Pi, Fmaxcol, 2];
ListPlot[dataMax, PlotLabel → "FxIn Max vs. ϕ",
 AxesLabel → {"ϕ (Deg)", "FxIn Max"}, ImageSize → Large, PlotRange → Full]
```

Out[22]=



In[23]:=
```
(*Checking Data Values: ϕ is left col, U/Rw is right col*)
dataTable = Join[ϕcol * 180 / Pi, Ucol, Fcol, 2];
Grid[Join[{{"ϕ (Deg)", "U", "FxIn[U]"}}, dataTable, 1]]
```

ϕ (Deg)	U	FxIn[U]
10.	0.00450688	7.8351×10^{-8}
11.	0.00484907	9.34992×10^{-8}
12.	0.00516831	1.08693×10^{-7}
13.	0.0054637	1.23644×10^{-7}
14.	0.00573433	1.3808×10^{-7}
15.	0.00597925	1.5175×10^{-7}
16.	0.0061975	1.64422×10^{-7}
17.	0.00638811	1.75883×10^{-7}
18.	0.00655009	1.85942×10^{-7}
19.	0.0066825	1.94426×10^{-7}
20.	0.00678441	2.01188×10^{-7}
21.	0.00685494	2.06103×10^{-7}
22.	0.00689327	2.09069×10^{-7}
23.	0.00689869	2.10013×10^{-7}
24.	0.00687057	2.08885×10^{-7}
25.	0.00680842	2.0567×10^{-7}
26.	0.00671192	2.00381×10^{-7}
27.	0.00658089	1.93065×10^{-7}
28.	0.00641539	1.83806×10^{-7}

Out[24]=

29.	0.00621568	1.72725×10^{-7}
30.	0.00598224	1.59986×10^{-7}
31.	0.00571585	1.45793×10^{-7}
32.	0.00541752	1.304×10^{-7}
33.	0.00508859	1.14104×10^{-7}
34.	0.00473063	9.72539×10^{-8}
35.	0.00434554	8.02475×10^{-8}
36.	0.00393549	6.35323×10^{-8}
37.	0.00350289	4.76042×10^{-8}
38.	0.00305045	3.30051×10^{-8}
39.	0.001	9.11988×10^{-7}
40.	0.001	6.4262×10^{-7}
41.	0.001	3.59188×10^{-7}
42.	0.001	6.22345×10^{-8}
43.	0.001	-2.47663×10^{-7}
44.	0.001	-5.69891×10^{-7}
45.	0.001	-9.03807×10^{-7}
46.	0.001	-1.24874×10^{-6}
47.	0.001	-1.60398×10^{-6}
48.	0.001	-1.9688×10^{-6}
49.	0.001	-2.34247×10^{-6}
50.	0.001	-2.7242×10^{-6}
51.	0.001	-3.11322×10^{-6}
52.	0.001	-3.50872×10^{-6}
53.	0.001	-3.9099×10^{-6}
54.	0.001	-4.31595×10^{-6}
55.	0.001	-4.72605×10^{-6}
56.	0.001	-5.13937×10^{-6}
57.	0.001	-5.55512×10^{-6}
58.	0.001	-5.97248×10^{-6}
59.	0.001	-6.39069×10^{-6}
60.	0.001	-6.80897×10^{-6}
61.	0.001	-7.2266×10^{-6}
62.	0.001	-7.64286×10^{-6}
63.	0.001	-8.05712×10^{-6}
64.	0.001	-8.46877×10^{-6}
65.	0.001	-8.87726×10^{-6}
66.	0.001	-9.28214×10^{-6}
67.	0.001	-9.68305×10^{-6}
68.	0.001	-0.0000100797
69.	0.001	-0.0000104721
70.	0.001	-0.0000108601
71.	0.001	-0.0000112442
72.	0.001	-0.0000116248
73.	0.001	-0.0000120027
74.	0.001	-0.0000123794
75.	0.001	-0.0000127567
76.	0.001	-0.0000131372
77.	0.001	-0.0000135246

78.	0.001	−0.0000139241
79.	0.001	−0.0000143429
80.	0.001	−0.0000147915
81.	0.001	−0.0000152852
82.	0.001	−0.0000158473
83.	0.001	−0.0000165145
84.	0.001	−0.0000173485
85.	0.001	−0.0000184605
86.	0.001	−0.000020073
87.	0.001	−0.0000227059
88.	0.001	−0.0000279189
89.	0.001	−0.0000435114

ϕ = 23° yields the highest value for U (m/s).