McGill University

Department of Engineering

MECH530
Mechanics of Composite Materials

Assignment 6

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Contents

Design 1

Geometric properties of the layup

For this design, a $[\pm 54_3]_S$ layup of AS4/PEEK (12 layers in total) is used. The Figure 1 Shows the geometric properties of the material. The Figure 2 shows the *A, a, D* and *d* matrices and the Figure 3 the loads applied.

Material	Properties	aphite/thermoplastic	
Graphite/epoxy (T300/N5208)	Ex	134	GPa
	Ey	8,9	GPa
Fiberglass (E-glass/epoxy)	Es	5,1	GPa
	vx	0,28	-
Kevlar/epoxy (Kev49/epoxy)	Xt	2130	MPa
	Xc	1100	MPa
Graphite/epoxy (AS/H3501)	Yt	80	MPa
	Yc	200	MPa
Graphite/thermoplastic (AS4/PEEK)	Sc	160	MPa
	Thickness	0,125	mm
	vy	0,0186	-

Geometry

RUN

N	12	-
Half-core thickness	0,0	m
M	1,005	-
Thickness of all plys	0,0015	m
h*	2,81E-10	m

Layer	O. Angle	m	n
1	54	0,588	0,809
2	-54	0,588	-0,809
3	54	0,588	0,809
4	-54	0,588	-0,809
5	54	0,588	0,809
6	-54	0,588	-0,809
7	-54	0,588	-0,809
8	54	0,588	0,809
9	-54	0,588	-0,809
10	54	0,588	0,809
11	-54	0,588	-0,809
12	54	0,588	0,809

On-axis [S] matrice [1/GPa]

[S]	σx	σy	σs
εx	0,007	-0,0021	-
εy	-0,002	0,1124	-
εs	-	-	0,1961

On-axis [Q] matrice [GPa]

[Q]	εx	εy	εs
σx	134,701	2,505	-
σy	2,505	8,947	-
σs	-	-	5,100

Figure 1: Geometric properties

A matrix [GN/m]

0,0385	0,0439	0,0000
0,0439	0,0968	0,0000
0,0000	0,0000	0,0478

a matrix [m/GN]

53,7485	-24,3610	0,0000
-24,3610	21,3745	0,0000
0,0000	0,0000	20,9401

D matrix [kNm]

0,0072	0,0082	0,0015
0,0082	0,0181	0,0027
0,0015	0,0027	0,0090

d matrix [1/kNm]

287,3190	-128,9087	-8,7993
-128,9087	115,5616	-13,5434
-8,7993	-13,5434	117,2502

Figure 2: A, a, D and d matrices ([B]=0)

N		
N 1	5,40E+04	N/m
N 2	1,08E+05	N/m
N 6	0,00E+00	N/m

Figure 3: Loads applied ([M]=0)

R factors

The Figure 4 shows the security factor for all the 3 failure criteria. For this layup, the lowest R factor is 5.6 (Tsai Wu^{+}) and it cannot be maximised.

Ply		Angle	σx [GPa]	σy [GPa]	σs [GPa]	FT (X)	FC (X')	MT (Y)	MC (Y')	S (S)	(+)	(-)	FT	FC	MT	MC
T	1	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	1	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	2	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	2	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	3	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	3	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	4	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	4	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	5	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	5	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	6	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	6	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	7	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	7	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	8	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	8	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	9	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	9	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	10	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	10	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	11	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	11	-54	1,01E-01	6,52E-03	-3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
T	12	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A
B	12	54	1,01E-01	6,52E-03	3,50E-03	20,910	N/A	12,210	N/A	45,710	5,600	-25,000	19,000	N/A	11,800	N/A

Figure 4: R factor for each layer pf the ply under the applied load. R=5.6 is the lowest R factor (Tsai-Wu^{+})

Design 2

10 layers

Geometric properties of the layup

For this exercise, several iterations are tested for 5 symmetric layers (10 layers in total). The best K factor obtained is with the following layup arrangement:

- $[-5/0/60/15/80]_S$ (10 layers in total).

Figure 5 shows the geometrical properties of the layup.

Material
Graphite/epoxy (T300/N5208)
Fiberglass (E-glass/epoxy)
Kevlar/epoxy (Kev49/epoxy)
Graphite/epoxy (AS/H3501)
Graphite/thermoplastic (AS4/PEEK)

Properties	Fiberglass	
Ex	38,6	GPa
Ey	8,27	GPa
Es	4,14	GPa
vx	0,26	-
Xt	1062	MPa
Xc	610	MPa
Yt	31	MPa
Yc	118	MPa
Sc	72	MPa
Thickness	0,125	mm
vy	0,0557	-

Geometry		
N	10	-
Half-core thickness	0	m
M	1,015	-
Thickness of all plys	0,00125	m
h*	1,63E-10	m

Layer	O. Angle	m	n
1	-5	0,996	-0,087
2	0	1,000	0,000
3	60	0,500	0,866
4	15	0,966	0,259
5	80	0,174	0,985
6	80	0,174	0,985
7	15	0,966	0,259
8	60	0,500	0,866
9	0	1,000	0,000
10	-5	0,996	-0,087

On-axis [S] matrice [1/GPa]

[S]	σx	σy	σs
εx	0,026	-0,0067	-
εy	-0,007	0,1209	-
εs	-	-	0,2415

On-axis [Q] matrice [GPa]

[Q]	εx	εy	εs
σx	39,167	2,182	-
σy	2,182	8,392	-
σs	-	-	4,140

Figure 5: Geometrical properties

D11, D22 and K factor

Table 1 present D11, D22 and the K factor.

Tableau 1: D11, D22 and K factor for $[-5/0/60/15/80]_S$ layup

D11	5,5719E-03
D22	1,8574E-03
K_{10}	2,99989103060751

Now, let's see if it's possible to obtain an acceptable K with 9 layers.

9 layers

Geometric properties of the layup

The best K factor obtained is with the following layup arrangement:

- $[-15/-5/60/0/-60/0/60/-5/-15]_T$ or $[-15/-5/60/0/\overline{-60}]_S$ (9 layers in total)

Figure 6 shows the geometrical properties of the layup.

Material
Graphite/epoxy (T300/N5208)
Fiberglass (E-glass/epoxy)
Kevlar/epoxy (Kev49/epoxy)
Graphite/epoxy (AS/H3501)
Graphite/thermoplastic (AS4/PEEK)

Properties	Fiberglass	
Ex	38,6	GPa
Ey	8,27	GPa
Es	4,14	GPa
vx	0,26	-
Xt	1062	MPa
Xc	610	MPa
Yt	31	MPa
Yc	118	MPa
Sc	72	MPa
Thickness	0,125	mm
vy	0,0557	-

Geometry		
N	9	-
Half-core thickness		m
M	1,015	-
Thickness of all plys	0,001125	m
h*	1,1865E-10	m

Layer	O. Angle	m	n
1	-15	0,966	-0,259
2	-5	0,996	-0,087
3	60	0,500	0,866
4	0	1,000	0,000
5	-60	0,500	-0,866
6	0	1,000	0,000
7	60	0,500	0,866
8	-5	0,996	-0,087
9	-15	0,966	-0,259

On-axis [S] matrice [1/GPa]

[S]	σx	σy	σs
εx	0,026	-0,0067	-
εy	-0,007	0,1209	-
εs	-	-	0,2415

On-axis [Q] matrice [GPa]

[Q]	εx	εy	εs
σx	39,167	2,182	-
σy	2,182	8,392	-
σs	-	-	4,140

Figure 6: Geometric properties

D11, D22 and K factor

Table 2 present D11, D22 and the K factor.

Tableau 2: D11, D22 and K factor for $[-15/-5/60/0/-60/0/60/-5/-15]_T$ layup

D11	3,9454E-09
D22	1,3132E-09
K_9	3,00431835974843

Conclusion

- $|3.00 - K_{10}| < |3.00 - K_9|$ but,
- 9 layers < 10 layers

Design 3

Geometric properties of the layup

For this design exercise, a layup $[5/0_2/\pm 20/40/\pm 40]_S$ of T300/N5208 is used (16 layers in total). Figure 7 shows the geometric properties of the layup. Figure 8 shows *A, a, D* and *d* matrices. Figure 9 shows the 2 cases of load applied on the top of the violin.

Material	Properties	ite/epoxy (T300/N5208)		Geometry		
Graphite/epoxy (T300/N5208)	Ex	181	GPa			
	Ey	10,3	GPa			
Fiberglass (E-glass/epoxy)	Es	7,17	GPa			
	vx	0,28	-	N	16	-
Kevlar/epoxy (Kev49/epoxy)	Xt	1500	MPa			
	Xc	1500	MPa	Half-core thickness	0,00075	m
Graphite/epoxy (AS/H3501)	Yt	40	MPa			
	Yc	246	MPa	M	1,004	-
	Sc	68	MPa			
Graphite/thermoplastic (AS4/PEEK)	Thickness	0,125	mm	Thickness of all plys	0,002	m
	vy	0,0159	-	h*	3,2917E-09	m

Layer	O. Angle	m	n
1	5	0,996	0,087
2	0	1,000	0,000
3	0	1,000	0,000
4	20	0,940	0,342
5	-20	0,940	-0,342
6	40	0,766	0,643
7	40	0,766	0,643
8	-40	0,766	-0,643
9	-40	0,766	-0,643
10	40	0,766	0,643
11	40	0,766	0,643
12	-20	0,940	-0,342
13	20	0,940	0,342
14	0	1,000	0,000
15	0	1,000	0,000
16	5	0,996	0,0872

On-axis [S] matrice [1/GPa]

[S]	σx	σy	σs
εx	0,006	-0,0015	-
εy	-0,002	0,0971	-
εs	-	-	0,1395

On-axis [Q] matrice [GPa]

[Q]	εx	εy	εs
σx	181,811	2,897	-
σy	2,897	10,346	-
σs	-	-	7,170

Off-axis [S] matrice [1/GPa]

layer number: 1

0,0065	-0,0018	-0,0108
-0,0018	0,0966	-0,0051
-0,0108	-0,0051	0,1385

Figure 7: Geometric properties

A matrix [GN/m]

0,2630	0,0429	0,0158
0,0429	0,0471	0,0090
0,0158	0,0090	0,0515

a matrix [m/GN]

4,4892	-3,9619	-0,6808
-3,9619	25,4863	-3,2641
-0,6808	-3,2641	20,2170

D matrix [kNm]

0,4953	0,0487	0,0303
0,0487	0,0589	0,0131
0,0303	0,0131	0,0628

d matrix [1/kNm]

2,2284	-1,6816	-0,7243
-1,6816	19,0809	-3,1716
-0,7243	-3,1716	16,9471

Figure 8: A, a, D, and d matrices

Load case 1

N			**M**		
N 1	-22,40	N/m	M 1	-990,00	Nm/m
N 2	-3,000	N/m	M 2	-99,000	Nm/m
N 6	-2,00	N/m	M 6	-100,00	Nm/m

Load case 2

N			**M**		
N 1	-20,80	N/m	M 1	-950,00	Nm/m
N 2	-2,800	N/m	M 2	-96,000	Nm/m
N 6	-2,20	N/m	M 6	-110,00	Nm/m

Figure 9: Case 1 and 2 applied in the top of the violin

R factor

The Figure 10 and 11 shows the security factor for all the 3 failure criteria for both load cases. For this layup 2,0 and 2,1 are the lowest R factor for case load 1 and 2 respectively. Thus, the design is safe.

Ply		Angle	σx [GPa]	σy [GPa]	σs [GPa]	FT (X)	FC (X')	MT (Y)	MC (Y')	S (S)	(+)	(-)	FT	FC	MT	MC
T	1	5	-6,39E-01	-7,74E-03	-3,71E-03	N/A	2,310	N/A	31,710	18,310	3,000	-2,100	N/A	2,300	N/A	19,600
B	1	5	-5,93E-01	-7,19E-03	-3,45E-03	N/A	2,510	N/A	34,210	19,710	3,300	-2,300	N/A	2,500	N/A	21,100
T	2	0	-5,81E-01	-7,70E-03	-7,73E-03	N/A	2,510	N/A	31,910	8,710	3,300	-2,200	N/A	2,500	N/A	10,300
B	2	0	-5,36E-01	-7,11E-03	-7,14E-03	N/A	2,710	N/A	34,610	9,510	3,600	-2,400	N/A	2,700	N/A	11,200
T	3	0	-5,36E-01	-7,11E-03	-7,14E-03	N/A	2,710	N/A	34,610	9,510	3,600	-2,400	N/A	2,700	N/A	11,200
B	3	0	-4,91E-01	-6,51E-03	-6,54E-03	N/A	3,010	N/A	37,710	10,310	3,900	-2,600	N/A	3,000	N/A	12,200
T	4	20	-4,85E-01	-6,80E-03	8,04E-03	N/A	3,010	N/A	36,110	8,410	3,900	-2,600	N/A	3,000	N/A	9,900
B	4	20	-4,41E-01	-6,18E-03	7,31E-03	N/A	3,310	N/A	39,710	9,210	4,300	-2,800	N/A	3,400	N/A	10,900
T	5	-20	-3,45E-01	-1,02E-02	-1,64E-02	N/A	4,310	N/A	24,210	4,110	4,400	-2,300	N/A	4,300	N/A	4,700
B	5	-20	-3,11E-01	-9,14E-03	-1,48E-02	N/A	4,810	N/A	26,910	4,510	4,900	-2,600	N/A	4,800	N/A	5,200
T	6	40	-2,97E-01	-9,72E-03	1,54E-02	N/A	5,010	N/A	25,210	4,310	4,900	-2,500	N/A	5,000	N/A	5,000
B	6	40	-2,64E-01	-8,64E-03	1,37E-02	N/A	5,610	N/A	28,410	4,910	5,600	-2,800	N/A	5,600	N/A	5,700
T	7	40	-2,64E-01	-8,64E-03	1,37E-02	N/A	5,610	N/A	28,410	4,910	5,600	-2,800	N/A	5,600	N/A	5,700
B	7	40	-2,31E-01	-7,56E-03	1,20E-02	N/A	6,410	N/A	32,510	5,610	6,400	-3,200	N/A	6,500	N/A	6,500
T	8	-40	-1,28E-01	-1,18E-02	-1,35E-02	N/A	11,610	N/A	20,710	5,010	7,500	-2,700	N/A	11,600	N/A	5,900
B	8	-40	-1,10E-01	-1,01E-02	-1,15E-02	N/A	13,610	N/A	24,210	5,810	8,700	-3,100	N/A	13,600	N/A	6,900
T	9	-40	1,10E-01	1,01E-02	1,15E-02	13,610	N/A	3,910	N/A	5,810	3,000	-8,800	5,400	N/A	3,200	N/A
B	9	-40	1,28E-01	1,18E-02	1,35E-02	11,610	N/A	3,310	N/A	5,010	2,600	-7,600	4,600	N/A	2,800	N/A
T	10	40	2,31E-01	7,56E-03	-1,20E-02	6,410	N/A	5,210	N/A	5,610	3,100	-6,500	4,200	N/A	3,800	N/A
B	10	40	2,64E-01	8,64E-03	-1,37E-02	5,610	N/A	4,610	N/A	4,910	2,700	-5,700	3,700	N/A	3,300	N/A
T	11	40	2,64E-01	8,64E-03	-1,37E-02	5,610	N/A	4,610	N/A	4,910	2,700	-5,700	3,700	N/A	3,300	N/A
B	11	40	2,97E-01	9,72E-03	-1,54E-02	5,010	N/A	4,110	N/A	4,310	2,400	-5,000	3,300	N/A	3,000	N/A
T	12	-20	3,11E-01	9,14E-03	1,48E-02	4,810	N/A	4,310	N/A	4,510	2,500	-5,000	3,300	N/A	3,100	N/A
B	12	-20	3,45E-01	1,02E-02	1,64E-02	4,310	N/A	3,910	N/A	4,110	2,200	-4,500	2,900	N/A	2,800	N/A
T	13	20	4,41E-01	6,18E-03	-7,31E-03	3,310	N/A	6,410	N/A	9,210	2,700	-4,400	3,100	N/A	5,300	N/A
B	13	20	4,85E-01	6,80E-03	-8,04E-03	3,010	N/A	5,810	N/A	8,410	2,500	-4,000	2,900	N/A	4,800	N/A
T	14	0	4,91E-01	6,51E-03	6,54E-03	3,010	N/A	6,110	N/A	10,310	2,500	-4,000	2,900	N/A	5,200	N/A
B	14	0	5,36E-01	7,11E-03	7,14E-03	2,710	N/A	5,610	N/A	9,510	2,300	-3,700	2,600	N/A	4,800	N/A
T	15	0	5,36E-01	7,11E-03	7,14E-03	2,710	N/A	5,610	N/A	9,510	2,300	-3,700	2,600	N/A	4,800	N/A
B	15	0	5,81E-01	7,70E-03	7,73E-03	2,510	N/A	5,110	N/A	8,710	2,100	-3,400	2,400	N/A	4,400	N/A
T	16	5	5,93E-01	7,19E-03	3,45E-03	2,510	N/A	5,510	N/A	19,710	2,200	-3,400	2,500	N/A	5,300	N/A
B	16	5	6,39E-01	7,74E-03	3,71E-03	2,310	N/A	5,110	N/A	18,310	2,000	-3,100	2,300	N/A	4,900	N/A

Figure 10: Failure criteria analysis for case load 1. The lowest R is R=2.0.

Ply		Angle	σx [GPa]	σy [GPa]	σs [GPa]	FT (X)	FC (X')	MT (Y)	MC (Y')	S (S)	(+)	(-)	FT	FC	MT	MC
T	1	5	-6,15E-01	-6,65E-03	-6,43E-03	N/A	2,410	N/A	37,010	10,510	3,000	-2,200	N/A	2,400	N/A	12,400
B	1	5	-5,71E-01	-6,17E-03	-5,97E-03	N/A	2,610	N/A	39,810	11,310	3,200	-2,400	N/A	2,600	N/A	13,400
T	2	0	-5,54E-01	-6,90E-03	-1,02E-02	N/A	2,610	N/A	35,610	6,610	3,200	-2,300	N/A	2,700	N/A	7,700
B	2	0	-5,11E-01	-6,37E-03	-9,37E-03	N/A	2,910	N/A	38,510	7,210	3,500	-2,500	N/A	2,900	N/A	8,300
T	3	0	-5,11E-01	-6,37E-03	-9,37E-03	N/A	2,910	N/A	38,510	7,210	3,500	-2,500	N/A	2,900	N/A	8,300
B	3	0	-4,69E-01	-5,84E-03	-8,59E-03	N/A	3,110	N/A	42,110	7,910	3,800	-2,700	N/A	3,200	N/A	9,100
T	4	20	-4,80E-01	-5,36E-03	6,03E-03	N/A	3,110	N/A	45,910	11,210	3,800	-2,700	N/A	3,100	N/A	13,200
B	4	20	-4,36E-01	-4,87E-03	5,48E-03	N/A	3,410	N/A	50,510	12,310	4,200	-3,000	N/A	3,400	N/A	14,500
T	5	-20	-3,11E-01	-1,01E-02	-1,75E-02	N/A	4,810	N/A	24,310	3,810	4,400	-2,300	N/A	4,800	N/A	4,400
B	5	-20	-2,80E-01	-9,08E-03	-1,57E-02	N/A	5,310	N/A	27,010	4,310	4,900	-2,600	N/A	5,300	N/A	4,900
T	6	40	-3,04E-01	-8,08E-03	1,46E-02	N/A	4,910	N/A	30,410	4,610	4,800	-2,700	N/A	4,900	N/A	5,300
B	6	40	-2,70E-01	-7,18E-03	1,30E-02	N/A	5,510	N/A	34,210	5,210	5,400	-3,100	N/A	5,500	N/A	5,900
T	7	40	-2,70E-01	-7,18E-03	1,30E-02	N/A	5,510	N/A	34,210	5,210	5,400	-3,100	N/A	5,500	N/A	5,900
B	7	40	-2,37E-01	-6,28E-03	1,13E-02	N/A	6,310	N/A	39,110	5,910	6,200	-3,500	N/A	6,300	N/A	6,800
T	8	-40	-1,02E-01	-1,19E-02	-1,32E-02	N/A	14,610	N/A	20,710	5,110	7,700	-2,700	N/A	14,600	N/A	6,000
B	8	-40	-8,76E-02	-1,02E-02	-1,14E-02	N/A	17,110	N/A	24,110	5,910	9,000	-3,100	N/A	17,100	N/A	7,000
T	9	-40	8,76E-02	1,02E-02	1,14E-02	17,110	N/A	3,910	N/A	5,910	3,000	-9,100	5,600	N/A	3,200	N/A
B	9	-40	1,02E-01	1,19E-02	1,32E-02	14,610	N/A	3,310	N/A	5,110	2,600	-7,800	4,800	N/A	2,800	N/A
T	10	40	2,37E-01	6,28E-03	-1,13E-02	6,310	N/A	6,310	N/A	5,910	3,400	-6,300	4,300	N/A	4,300	N/A
B	10	40	2,70E-01	7,18E-03	-1,30E-02	5,510	N/A	5,510	N/A	5,210	3,000	-5,500	3,800	N/A	3,800	N/A
T	11	40	2,70E-01	7,18E-03	-1,30E-02	5,510	N/A	5,510	N/A	5,210	3,000	-5,500	3,800	N/A	3,800	N/A
B	11	40	3,04E-01	8,07E-03	-1,46E-02	4,910	N/A	4,910	N/A	4,610	2,600	-4,900	3,300	N/A	3,300	N/A
T	12	-20	2,80E-01	9,08E-03	1,57E-02	5,310	N/A	4,310	N/A	4,310	2,500	-5,000	3,300	N/A	3,000	N/A
B	12	-20	3,11E-01	1,01E-02	1,75E-02	4,810	N/A	3,910	N/A	3,810	2,200	-4,500	3,000	N/A	2,700	N/A
T	13	20	4,36E-01	4,87E-03	-5,48E-03	3,410	N/A	8,210	N/A	12,310	2,900	-4,300	3,300	N/A	6,800	N/A
B	13	20	4,80E-01	5,36E-03	-6,03E-03	3,110	N/A	7,410	N/A	11,210	2,600	-3,900	3,000	N/A	6,200	N/A
T	14	0	4,68E-01	5,84E-03	8,59E-03	3,110	N/A	6,810	N/A	7,910	2,600	-3,900	2,900	N/A	5,100	N/A
B	14	0	5,11E-01	6,37E-03	9,37E-03	2,910	N/A	6,210	N/A	7,210	2,400	-3,600	2,700	N/A	4,700	N/A
T	15	0	5,11E-01	6,37E-03	9,37E-03	2,910	N/A	6,210	N/A	7,210	2,400	-3,600	2,700	N/A	4,700	N/A
B	15	0	5,54E-01	6,90E-03	1,02E-02	2,610	N/A	5,710	N/A	6,610	2,200	-3,300	2,500	N/A	4,300	N/A
T	16	5	5,71E-01	6,17E-03	5,97E-03	2,610	N/A	6,410	N/A	11,310	2,300	-3,300	2,500	N/A	5,600	N/A
B	16	5	6,15E-01	6,65E-03	6,43E-03	2,410	N/A	6,010	N/A	10,510	2,100	-3,100	2,300	N/A	5,200	N/A

Figure 11:Failure criteria analysis for case load 2. The lowest R is R=2.1.

Mass of the laminate region

For this section, the mass is calculated with equation 1. The mass of the laminate region is 64 g.

Tableau 3: Properties of the layup

$\rho_{\mathrm{T300/N5208}}$	1,60e-3 g/mm^3
N	16 layers
h_0	0,125 mm
WL	20 000 mm^2

$$Mass = \rho \cdot N \cdot h_0 \cdot WB = 64\ g \tag{1}$$