EXTROVERT

ADVANCED CONCEPT EXPLORATION

ADL P-2011121202

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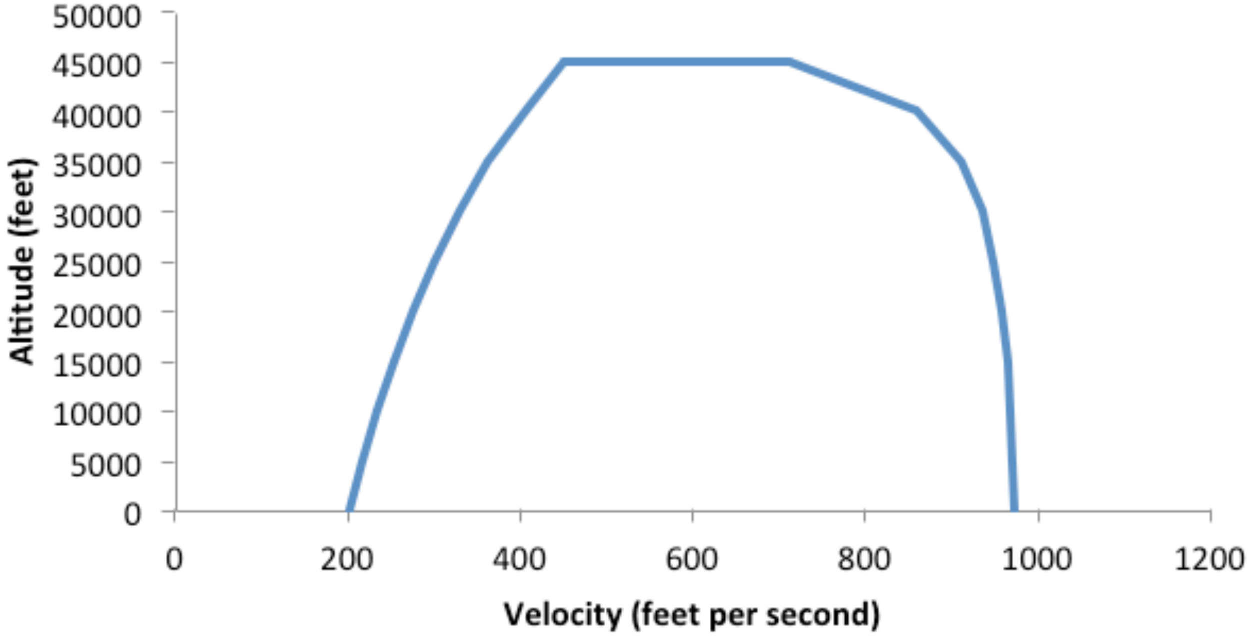
Missile Interceptor Design



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Publishing Information

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Disclaimer

Missile Interceptor

Update 10/12/2011

By Ian Moore and Kyle Carnahan

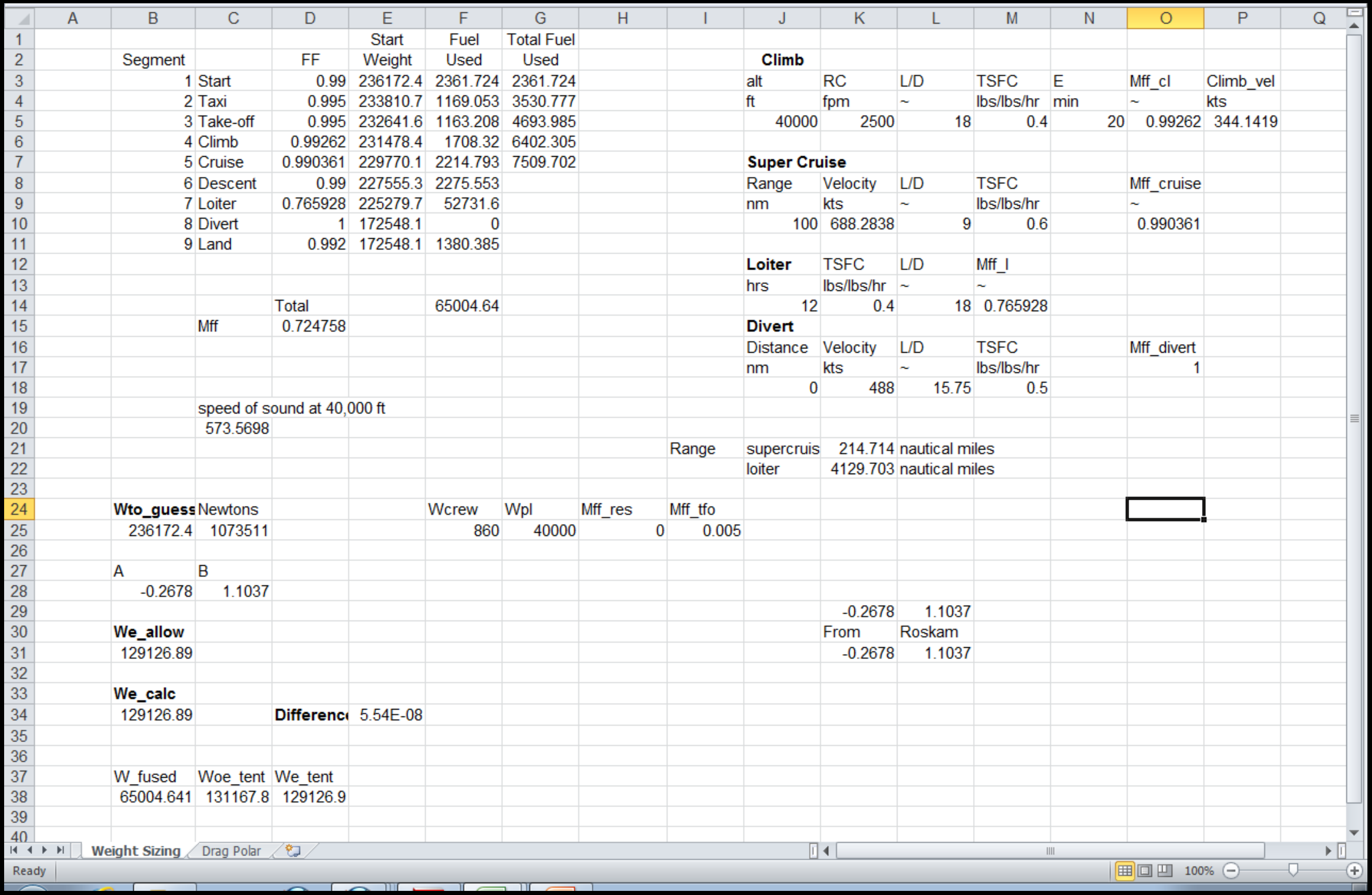
Transonic Patrol Craft

- Loiter at Mach 0.6 at 40,000 ft
- Carries 4 UCAV’s at 10,000 lb each
- Assumed loiter of 12 hours (2 a day)
- Capable of Mach 1.2 with afterburners for UCAV launch
- Coordinated turn (180 degs) at 1 minute

TPC Weight Sizing

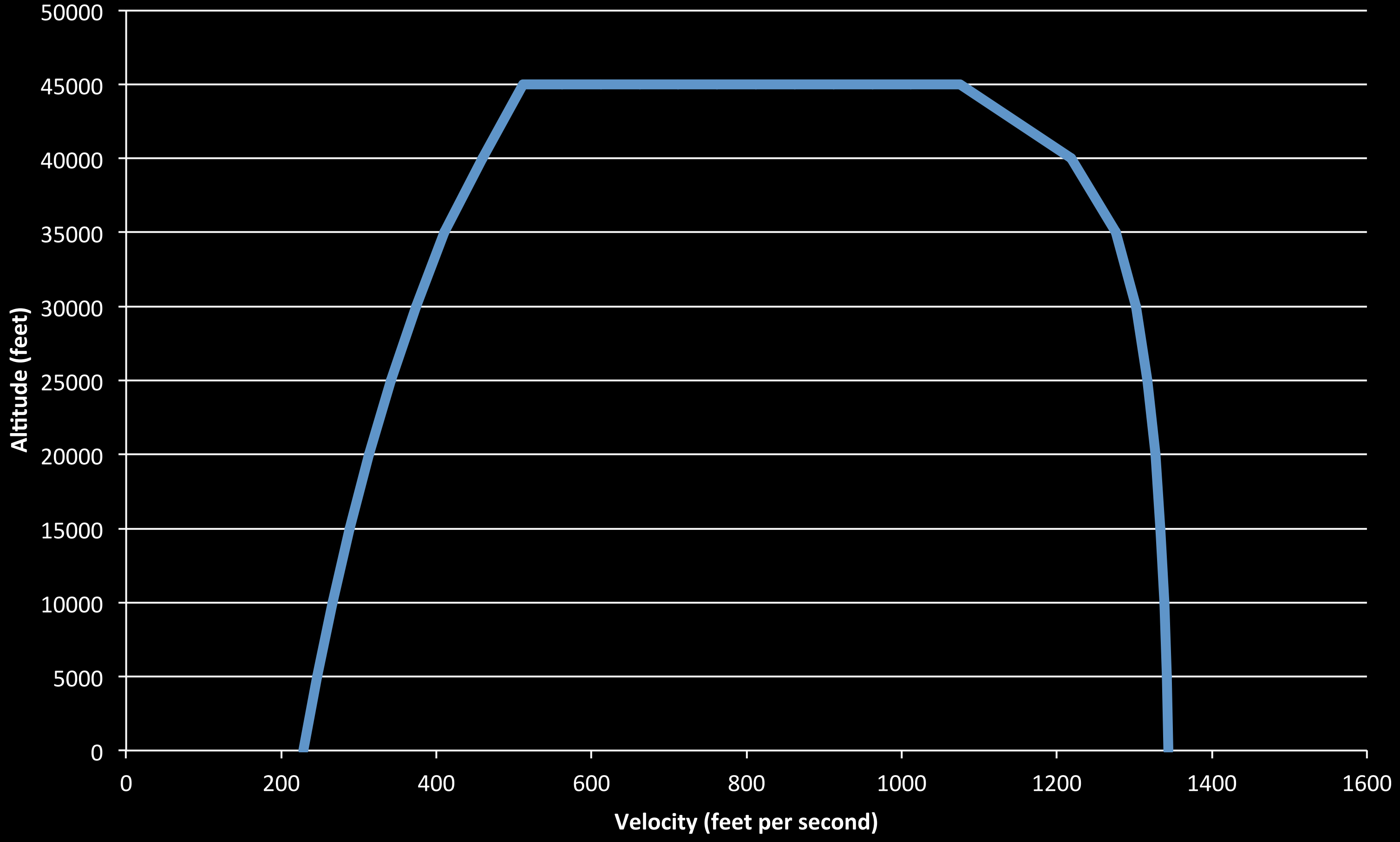
- Used historical values for linear W_{TO}/W_E regressions from Roskam's Airplane Design
- Used mission specification to determine fuel fractions and evaluated W_{TO}/W_E
- Compared the two answers and used Excel's Goal Seek until the two converged

TPC Calculations



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1					Start	Fuel	Total Fuel										
2		Segment		FF	Weight	Used	Used			**Climb**							
3		1	Start	0.99	236172.4	2361.724	2361.724			alt	RC	L/D	TSFC	E	Mff_cl	Climb_vel	
4		2	Taxi	0.995	233810.7	1169.053	3530.777			ft	fpm	~	lbs/lbs/hr	min	~	kts	
5		3	Take-off	0.995	232641.6	1163.208	4693.985			40000	2500	18	0.4	20	0.99262	344.1419	
6		4	Climb	0.99262	231478.4	1708.32	6402.305										
7		5	Cruise	0.990361	229770.1	2214.793	7509.702			**Super Cruise**							
8		6	Descent	0.99	227555.3	2275.553				Range	Velocity	L/D	TSFC		Mff_cruise		
9		7	Loiter	0.765928	225279.7	52731.6				nm	kts	~	lbs/lbs/hr		~		
10		8	Divert	1	172548.1	0				100	688.2838	9	0.6		0.990361		
11		9	Land	0.992	172548.1	1380.385											
12										**Loiter**	TSFC	L/D	Mff_l				
13										hrs	lbs/lbs/hr	~	~				
14				Total		65004.64				12	0.4	18	0.765928				
15			Mff	0.724758						**Divert**							
16										Distance	Velocity	L/D	TSFC		Mff_divert		
17										nm	kts	~	lbs/lbs/hr		1		
18										0	488	15.75	0.5				
19			speed of sound at 40,000 ft														
20			573.5698														
21									Range	supercruis	214.714	nautical miles					
22										loiter	4129.703	nautical miles					
23																	
24		**Wto_guess**	Newtons			Wcrew	Wpl	Mff_res	Mff_tfo								
25		236172.4	1073511			860	40000	0	0.005								
26																	
27		A	B														
28		-0.2678	1.1037														
29											-0.2678	1.1037					
30		**We_allow**									From	Roskam					
31		129126.89									-0.2678	1.1037					
32																	
33		**We_calc**															
34		129126.89		**Differenc**	5.54E-08												
35																	
36																	
37		W_fused	Woe_tent	We_tent													
38		65004.641	131167.8	129126.9													
39																	
40																	

Projected Flight Envelope



Assume mid-cruise: weight = 180,000 lbs

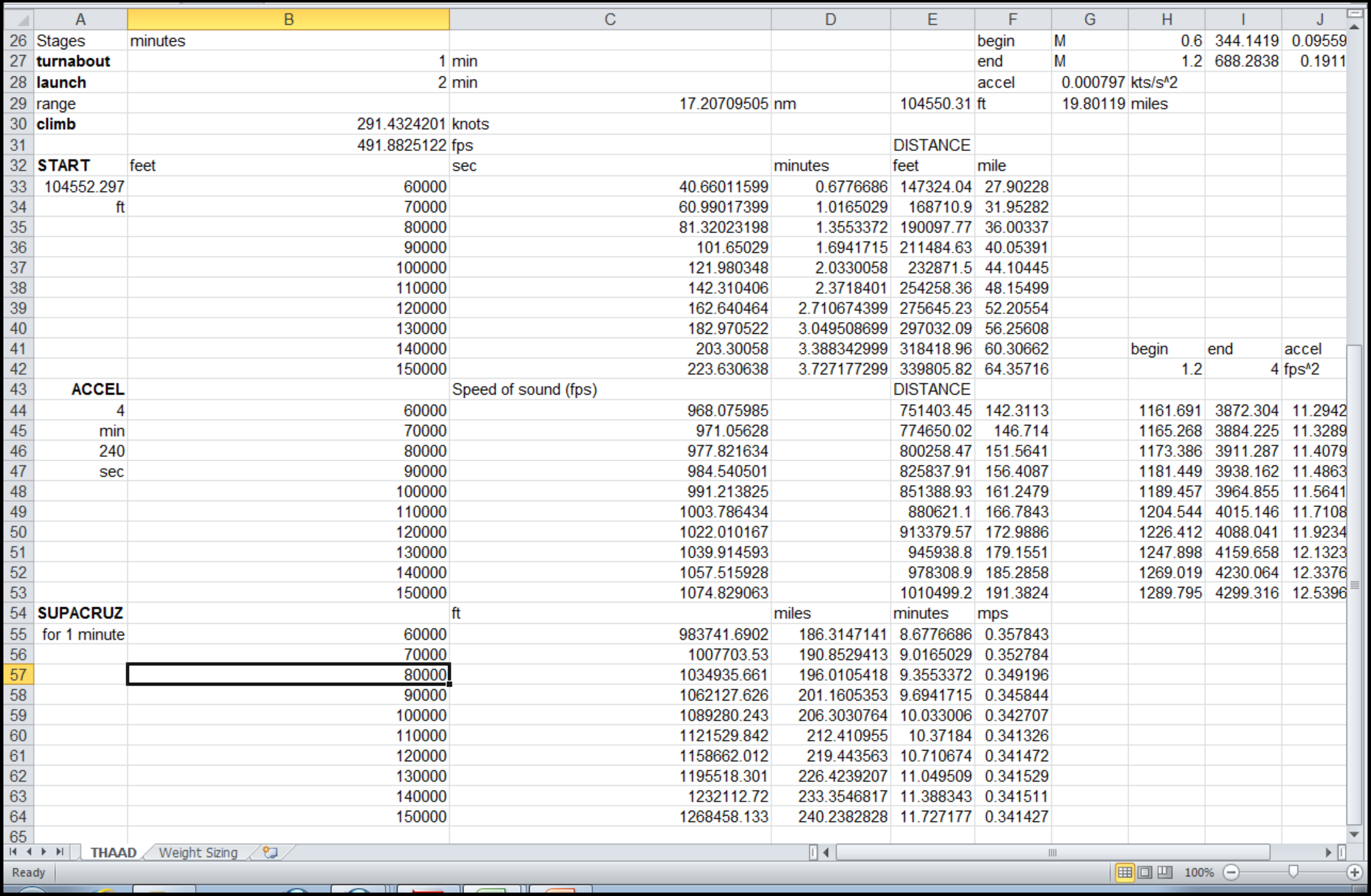
TPC Mission performance

- Assumed values from Roskam Airplane Design for military patrol jet
- Total weight ~1MN or 236,000 lbs
- L/D at loiter = 18
- TSFC = .4
- Supercruise L/D = 9 at Mach 1.2
- Payload of 40,000 lbs
- Crew weight of 860 lbs (4 people at 215 lbs each)
- Fuel fractions for cruise and loiter are based off Bruguet's Range and Endurance Equations
- Total range of TPC = 4340 nautical miles

UCAV

- Launched from TPC at 40,000 ft, Mach 1.2
- Carries 4 hypersonic, air breathing weapons
- Climb from 40,000 ft to 60,000-150,000 ft
- Supa Cruz at Mach 4
- Safely glides back to surface landing with or without launching weapons
- Note: gross simplifications made for linear acceleration, range, and climb parameters, will refine later

UCAV Calculations



	A	B	C	D	E	F	G	H	I	J
26	Stages	minutes				begin	M	0.6	344.1419	0.09559
27	**turnabout**	1	min			end	M	1.2	688.2838	0.1911
28	**launch**	2	min			accel	0.000797	kts/s^2		
29	range		17.20709505	nm	104550.31	ft	19.80119	miles		
30	**climb**	291.4324201	knots							
31		491.8825122	fps		DISTANCE					
32	**START**	feet	sec	minutes	feet	mile				
33	104552.297	60000	40.66011599	0.6776686	147324.04	27.90228				
34	ft	70000	60.99017399	1.0165029	168710.9	31.95282				
35		80000	81.32023198	1.3553372	190097.77	36.00337				
36		90000	101.65029	1.6941715	211484.63	40.05391				
37		100000	121.980348	2.0330058	232871.5	44.10445				
38		110000	142.310406	2.3718401	254258.36	48.15499				
39		120000	162.640464	2.710674399	275645.23	52.20554				
40		130000	182.970522	3.049508699	297032.09	56.25608				
41		140000	203.30058	3.388342999	318418.96	60.30662		begin	end	accel
42		150000	223.630638	3.727177299	339805.82	64.35716		1.2	4	fps^2
43	**ACCEL**		Speed of sound (fps)		DISTANCE					
44	4	60000	968.075985		751403.45	142.3113		1161.691	3872.304	11.2942
45	min	70000	971.05628		774650.02	146.714		1165.268	3884.225	11.3289
46	240	80000	977.821634		800258.47	151.5641		1173.386	3911.287	11.4079
47	sec	90000	984.540501		825837.91	156.4087		1181.449	3938.162	11.4863
48		100000	991.213825		851388.93	161.2479		1189.457	3964.855	11.5641
49		110000	1003.786434		880621.1	166.7843		1204.544	4015.146	11.7108
50		120000	1022.010167		913379.57	172.9886		1226.412	4088.041	11.9234
51		130000	1039.914593		945938.8	179.1551		1247.898	4159.658	12.1323
52		140000	1057.515928		978308.9	185.2858		1269.019	4230.064	12.3376
53		150000	1074.829063		1010499.2	191.3824		1289.795	4299.316	12.5396
54	**SUPACRUZ**		ft	miles	minutes	mps				
55	for 1 minute	60000	983741.6902	186.3147141	8.6776686	0.357843				
56		70000	1007703.53	190.8529413	9.0165029	0.352784				
57		80000	1034935.661	196.0105418	9.3553372	0.349196				
58		90000	1062127.626	201.1605353	9.6941715	0.345844				
59		100000	1089280.243	206.3030764	10.033006	0.342707				
60		110000	1121529.842	212.410955	10.37184	0.341326				
61		120000	1158662.012	219.443563	10.710674	0.341472				
62		130000	1195518.301	226.4239207	11.049509	0.341529				
63		140000	1232112.72	233.3546817	11.388343	0.341511				
64		150000	1268458.133	240.2382828	11.727177	0.341427				
65										

UCAV Mission performance

- 9-12 minutes to go from alert, launch from TPC, climb, and reach Mach 4 depending on altitude
- Assumed initial weight of 10,000 lbs
- 3500lbs of fuel and four hypersonic weapons

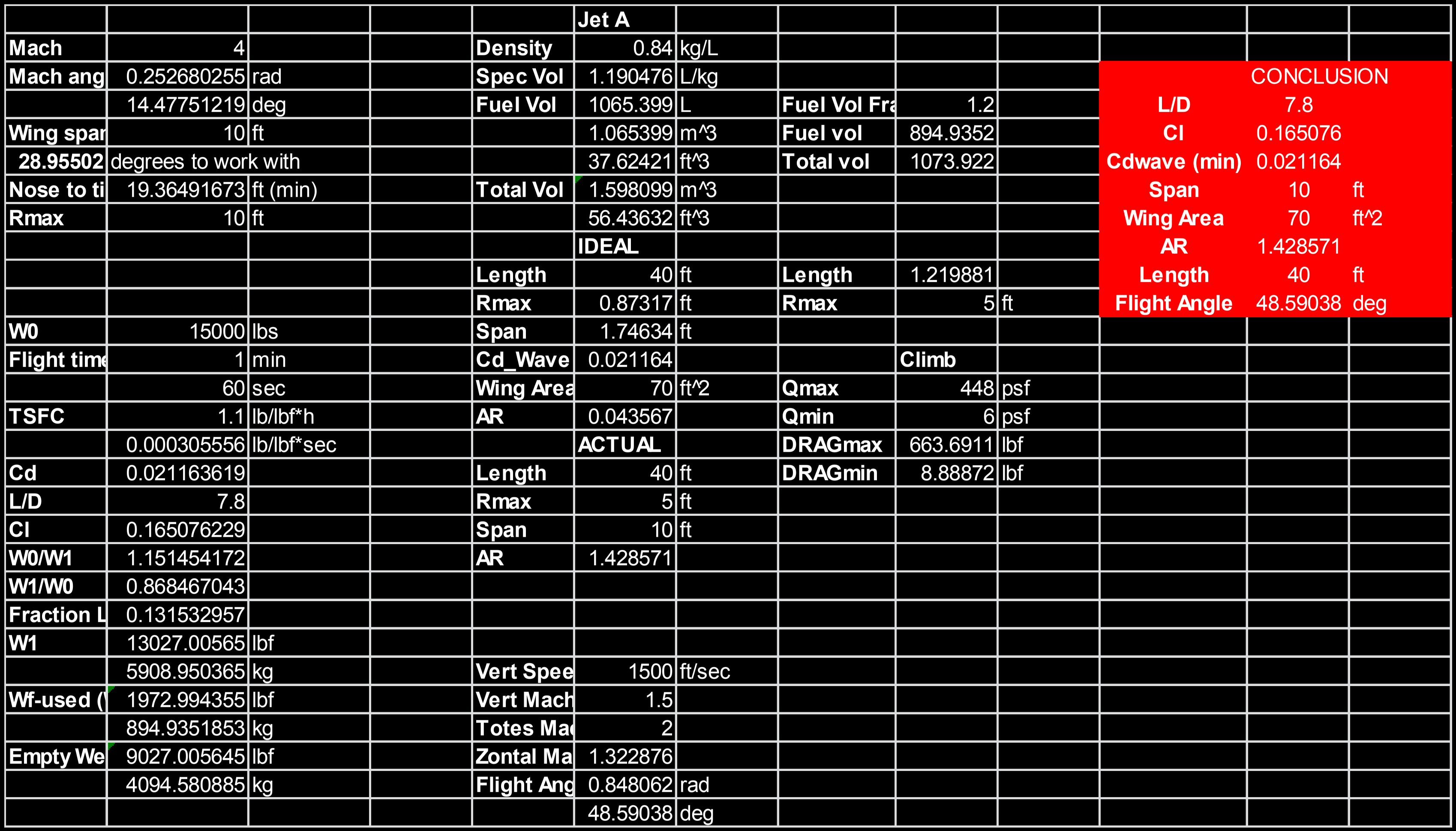
Jet Actuated Medium Range Air-to-Air Missile (JAMRAAM)

- 1000lbs each, air breathing SCRAMJET engines
- Hypersonic, Mach 8
- Launched at Mach 4 at 60,000-150,000 ft
- Climb to 60,000-250,000 ft
- Kinetic kill or near-field explosion
- Tangent Cone Method for shape design?

THAAD Specs Comparison

Length	6.17 m (20 ft 3 in)	
Diameter	booster: 34 cm (13.4 in); KV: 37 cm (14.5 in)	
Weight	900 kg (2000 lb)	
Speed	2800 m/s (9200 fps)	
Ceiling	150 km (93 miles)	
Range	> 200 km (125 miles)	
Propulsion	Pratt & Whitney solid-fueled rocket	
Warhead	none ("hit-to-kill")	
countdown	2	min
Payload	40	kg
Isp	300	sec

UCAV DRAG UPDATE



					Jet A							
Mach	4			**Density**	0.84	kg/L						
Mach ang	0.252680255	rad		**Spec Vol**	1.190476	L/kg				CONCLUSION		
	14.47751219	deg		**Fuel Vol**	1065.399	L	**Fuel Vol Fra**	1.2		**L/D**	7.8	
Wing spar	10	ft			1.065399	m^3	**Fuel vol**	894.9352		**Cl**	0.165076	
28.95502	degrees to work with				37.62421	ft^3	**Total vol**	1073.922		**Cdwave (min)**	0.021164	
Nose to ti	19.36491673	ft (min)		**Total Vol**	1.598099	m^3				**Span**	10	ft
Rmax	10	ft			56.43632	ft^3				**Wing Area**	70	ft^2
					IDEAL					**AR**	1.428571	
				Length	40	ft	**Length**	1.219881		**Length**	40	ft
				Rmax	0.87317	ft	**Rmax**	5	ft	**Flight Angle**	48.59038	deg
W0	15000	lbs		**Span**	1.74634	ft						
Flight time	1	min		**Cd_Wave**	0.021164			**Climb**				
	60	sec		**Wing Area**	70	ft^2	**Qmax**	448	psf			
TSFC	1.1	lb/lbf*h		**AR**	0.043567		**Qmin**	6	psf			
	0.000305556	lb/lbf*sec			**ACTUAL**		**DRAGmax**	663.6911	lbf			
Cd	0.021163619			**Length**	40	ft	**DRAGmin**	8.88872	lbf			
L/D	7.8			**Rmax**	5	ft						
Cl	0.165076229			**Span**	10	ft						
W0/W1	1.151454172			**AR**	1.428571							
W1/W0	0.868467043											
Fraction L	0.131532957											
W1	13027.00565	lbf										
	5908.950365	kg		**Vert Spee**	1500	ft/sec						
Wf-used (	1972.994355	lbf		**Vert Mach**	1.5							
	894.9351853	kg		**Totes Mac**	2							
Empty We	9027.005645	lbf		**Zontal Ma**	1.322876							
	4094.580885	kg		**Flight Ang**	0.848062	rad						
					48.59038	deg						

10/26/2011 Update

- Using Sears-Haack estimate for minimum wave drag, we estimated our Cd_wave at a minimum of 0.021164
- Our UCAV should be at least 15,000lb, not 10,000lb
- 40ft length
- Climb at ~49 degrees at M~2
- AR~1.43

10/31/2011 Update

- Re-assessed weight sizing for UCAV and TPC
- Re-assessed flight envelope for TPC
- Adjusted envelope for decreased wing loading, increased weight, and increased sea-level thrust available
- Adjusted Sears-Haack approximation

11/07/2011 Update

- We will now use rockets to accelerate UCAV from TPC
- TPC will now only travel at M=0.6
- Used more realistic TSFC and L/D during climb, and times for UCAV mission profile

Mach	4
Mach angle	0.252680255rad
	14.47751219deg
Wing span	10ft
28.95502	degrees to work with
Nose to tip	19.36491673ft (min)
Rmax	10ft

Climb

W0	8500lbs
Flight time	5min
	300sec
TSFC	4.1lb/lbf*h
	0.001138889lb/lbf*sec
Cd	0.027719051
L/D	7.5
Cl	0.207892881
W0/W1	1.046609148
W1/W0	0.95546652
Fraction Lost	0.04453348
W1	8121.465417lbf
	3683.834746kg
Wf-used (Wf)	378.5345832lbf
	171.7003987kg

Accelerate

L/D	8
TSFC	8.2
g's accel	1.5
Vel2accel	590.084638min m/s
	655.1553062max m/s
Time	40.10089283sec
	44.52295659sec
W1/W2	1.011483045
W2/W1	0.988647318
W2	8029.265005
Fraction Lost 2	0.011352682
Wf-used	470.7349951lbf
Empty Weight	4029.265005lbf

Jet A

Density	0.84kg/L
Spec Vol	1.190476L/kg
Fuel Vol	204.4052L
	0.204405m^3
	7.218503ft^3
Total Vol	0.511013m^3
	18.04626ft^3

IDEAL

Length	25ft
Rmax	0.624558ft
Span	1.249117ft
Cd_Wave	0.027719
Wing Area	70ft^2
AR	0.02229

ACTUAL

Length	25ft
Rmax	5ft
Span	10ft
AR	1.428571
Vert Speed	300ft/sec
Vert Mach	0.3
Totes Mach	2
Zontal Mach	1.977372
Flight Angle	0.150568rad
	8.626927deg

60000ft	0.000224slugs/ft^3	216.65K
150000ft	0.000003slugs/ft^3	267.066K

Fuel Vol Frac	1.2
Fuel vol	171.7004
Total vol	206.0405
Length	1.083537
Rmax	3ft

Climb

Qmax	448psf
Qmin	6psf
DRAGmax	869.2694lbf
DRAGmin	11.642lbf

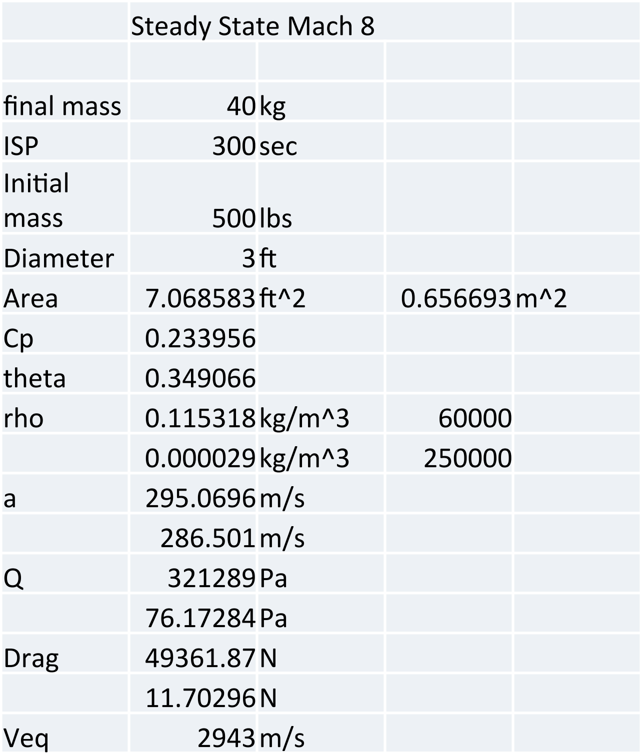
Climb

CONCLUSION

L/D	7.5	
Cl	0.207893	
Cdwave (min)	0.027719	
Span	10	ft
Wing Area	70	ft^2
AR	1.428571	
Length	25	ft
Flight Angle	8.626927	deg

11/20/2011 Update

- Rocket analysis was performed at Mach 8
- Newtonian drag analysis
- Rocket equations



	Steady State Mach 8			
final mass	40	kg		
ISP	300	sec		
Initial mass	500	lbs		
Diameter	3	ft		
Area	7.068583	ft^2	0.656693	m^2
Cp	0.233956			
theta	0.349066			
rho	0.115318	kg/m^3	60000	
	0.000029	kg/m^3	250000	
a	295.0696	m/s		
	286.501	m/s		
Q	321289	Pa		
	76.17284	Pa		
Drag	49361.87	N		
	11.70296	N		
Veq	2943	m/s		

11/28/2011 Update

- Rocket weight was changed to 750lbs
- Worst Case Scenario (Max climb) range and time to respond was approximated
- Comparison to THAAD

		Worse Case Scenario						
						a	m travel	km travel
TPC	0.8	M	Launched	2	min	303.1736	29104.67	29.10467
UCAV	1-4	M	Accel	0.5	min	303.1736	22738.02	22.73802
	4	M	Climb	4	min	295.0696	279779.3	279.7793
	4	M	Cruise	2	min	295.0696	141633.4	141.6334
Missile	4-8	M	Accel	0.5	min	295.0696	53112.52	53.11252
	8	M	Climb	1	min	322.2688	109381.6	109.3816
			Response	10	min			
			Range	635.7495	km			

12/05/2011 Update

- Skin friction coefficient was determined for UCAV
- Skin drag was approximated for UCAV

V	3872.3039	fps
	4299.3163	fps
rho	0.000226	slugs/ft^3
	0.0000037	
m	3.511E-07	lb*s/ft^2
	2.969E-07	
l	25	ft
Tstar/Tinf = 1+. 1198*M^2	2.9168	
Re=rho*v*l /m	62314205	60000ft
	1339463.6	150000ft
minf/mstar	0.006	
	0.005	
Cf	0.0015455	
	0.0043094	
Cd0	0.0030911	
	0.0086187	

Final Summary

- After a number of iterative refinements, our values changed a great deal from our preliminary analysis
- The proceeding slides show our updated system
- TPC GTOW ~220,000lbs
- UCAV GTOW ~8,500lbs
- JAMRAAM GTOW ~750lbs

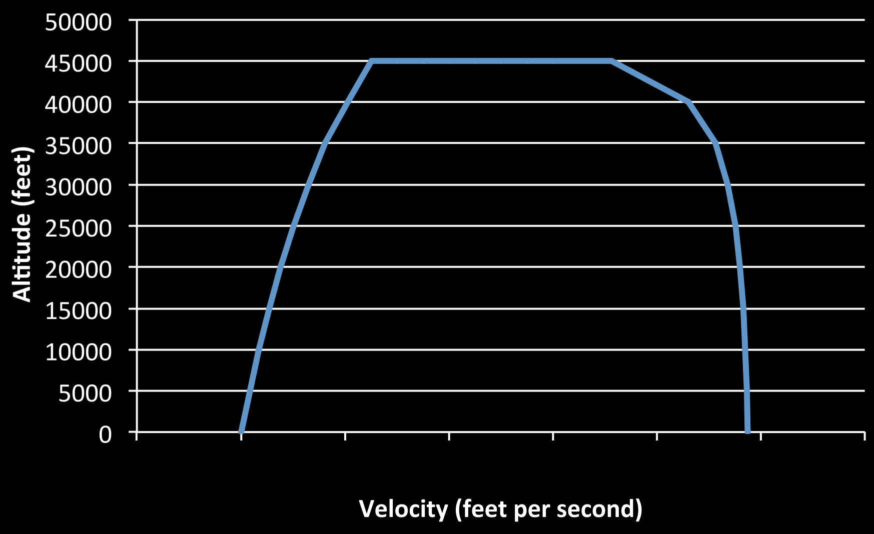
TPC

Mission Profile

Segment		FF	Start Weight (lbs)	Fuel Used (lbs)	Total Fuel Used (lbs)
1	Start	0.990	211418.9	2114.2	2114.2
2	Taxi	0.995	209304.7	1046.5	3160.7
3	Take-off	0.995	208258.2	1041.3	4202.0
4	Climb	0.993	207216.9	1529.3	5731.3
5	Accelerated Flight	0.990	205687.6	2056.9	7788.1
6	Loiter	0.766	203630.8	47664.2	55452.3
7	Land	0.992	155966.6	1247.7	56700.1

TPC

Flight Envelope



UCAV

Sears-Haack

	Sears-Haack	
Length	25	ft
Rmax	0.624558	ft
Span	1.249117	ft
Cd_Wave	0.027719	
Wing Area	70	ft^2
AR	0.02229	
	Actual	
Length	25	ft
Rmax	2.5	ft
Span	5	ft
AR	0.357143	
Wing Loading	121.4286	lbs/ft^2

UCAV

Skin Friction

	Value	Units
V	3872.3	fps
	4299.3	fps
rho	0.00023	slugs/ft^3
	0.0000037	
mu	3.51E-07	lb*s/ft^2
	2.97E-07	
length	25	ft
Tstar/Tinf = 1+.1198*M^2	2.92	
Re=rho*v*l/m	62,314,205	60000ft
	1,339,463.6	150000ft
minf/mstar	0.006	
	0.005	
Cf	0.0015455	
	0.0043094	

JAMRAAM

THAAD Comparison

	Steady State Mach 8	THAAD	
Final Mass	80	8	lbs
ISP	300	300	sec
Initial mass	750	2000	lbs
Diameter	1.5	1.21	ft
Area	1.77	1.15	ft^2
C_p	0.23	0.23	
theta	0.35	0.35	
rho	0.00022	~0	slugs/ft^3
	0.000000056		
a	968.08	~0	fps
	939.96		
Q	0.97	~0	psi
	0.00023		psi
Drag	57.94	~0	lbs
	0.013737		lbs
V_{eq}	9655.51	9655.51	fps
Range	~525000	>650000	ft
Ceiling	250000	492000	ft
Speed	7744.61	2800	fps
	7519.71		
Reaction Time	2	2	min

Final Profile

See written report for more details

	Worst Case Scenario					
		Mach	Time (min)	a (fps)	Distance (ft)	Distance (mi)
TPC	Launch	0.8	3	995	143232	27.13
UCAV	Climb	2	2	968	229478	43.46
	Accelerate	2-4	0.5	995	74600	14.13
	Cruise	4	4	968	929353	176.01
JAMRAAM	Accelerate	4-8	0.5	968	174254	33.00
	Climb	8	1	1057	358864	67.97
				Response	11	min
				Range	334.57	miles

AE-3051
MISSILE INTERCEPTOR DESIGN

Kyle Carnahan

Ian Moore

Introduction

The purpose of this study is to develop and analyze conceptual designs for the three different aircraft that form the Model AE3021BF11 Missile Interceptor. The purpose of this system is strategic deterrence, which is to say a defense system advanced and dominant enough that it discourages any ICBM attacks before they are launched. The architecture consists of three systems integrated at launch, but all based on aerodynamic vehicles rather than ground-launched rockets. All system components can be recovered with only some fuel expended, after launch. The final stage weapon is not launched unless there is a real threat to be hit, and that of course cannot be recovered. The hypersonic weapon is an explosive and/or kinetic kill device. The idea of the three stage response is to have aircraft loitering at Mach 0.6 around 40,000ft at all times, giving this new system a height and range advantage over ground-based rocket systems. A weight-sizing analysis was performed on the TPC to get a rough estimate of its baseline metrics. We assumed the UCAV (and hypersonic) would be contained fully within the cargo bay of a large C-130J-like aircraft, which would loiter at Mach 0.6 around 40,000 feet. Upon receiving the initial threat, we designed the TPC to accelerate to Mach 0.8 before launching one or more of the UCAV's. Weight-sizing analysis was also performed on the UCAV, as well as rough shape, wave and transonic drag, mission profile, and propulsion analysis. The UCAV would, upon leaving the TPC, use a small rocket boost through the transonic region to Mach 2.0 then climb between 20,000 and 90,000ft higher with one RAMJET engine and finally accelerate to Mach 4.0. Upon reaching the desired height and speed, the UCAV would either received an abort command (from HQ) and glide back down to ground station for collection and recycling back into use, or it would continue with the mission and launch the hypersonic JAMRAAM missile. We performed basic hypersonic lift-drag analysis on the missile by means of Newtonian aerodynamic analysis. We approximated the size and weight of the missile as well based on payload and fuel. From our analyses of the three-stage missile defense system, we have seen that such a system is technologically feasible, though probably not economically.

Transonic Patrol Craft (TPC)

The C-130J aircraft was taken as a baseline in our design of a new transonic patrol craft. We decided a mission profile which includes: start, taxi, take-off, a climb from sea level to 40,000 feet at a rate of 2,500ft/min, a loiter of 12 hours at Mach 0.6, a slight acceleration period to Mach 0.8 when launching the UCAV, and landing. The acceleration period to Mach 0.8 will be during a one minute turnabout to face the oncoming ICBM and prepare the UCAV's; the launch itself takes two minutes. A payload of 36,000 pounds was used (500lbs per rocket, 8500lbs per UCAV) along with 860lbs reserved for crew (to manage the TPC and monitor the UCAV's). Values were taken from *Roskam's Airplane Design Pt. 1* for a military transport aircraft to complete a linear weighted regression model of fuel fractions and GTOW. We assumed a TSFC of 0.4lbs/lbs/hr during climb and loiter. Based on historical data from similar aircraft given a Lift-to-drag ratio of 18, we predicted a GTOW of around 1,000,000N or 210,000lbs. Although the TPC is primarily used as a high altitude carrier of the UCAV and hypersonic missiles, it also has a loiter radius of 4,129 nautical miles from launch. With a 12 hour loiter it has a 4000+ nautical mile range and only needs to be refueled twice a day. Our mission profile can be seen below

Table 1 TPC mission profile

Segment		FF	Start Weight (lbs)	Fuel Used (lbs)	Total Fuel Used (lbs)
1	Start	0.990	211418.9	2114.2	2114.2
2	Taxi	0.995	209304.7	1046.5	3160.7
3	Take-off	0.995	208258.2	1041.3	4202.0
4	Climb	0.993	207216.9	1529.3	5731.3
5	Accelerated Flight	0.990	205687.6	2056.9	7788.1
6	Loiter	0.766	203630.8	47664.2	55452.3
7	Land	0.992	155966.6	1247.7	56700.1

Next, a flight envelope was developed for the TPC using equations for stall velocity, service ceiling, and thrust available from John D. Anderson, Jr.'s *Aircraft Performance and Design*. A wing loading of 70lbs/ft^2 was chosen based on historical data of similarly sized aircraft combined with requirements for flight at 40,000ft with our weight and sizing. Our wing area was found to be 3,020ft^2, which happens to be one third the wing area of the A380. Standard atmosphere was assumed. We realize that the service ceiling is not actually a horizontal line, but its exact calculation is unnecessary for our purposes; since we will be loitering at 40,000ft, an average was used. Also, the equation used does not consider the considerable drag increase that occurs at high transonic speeds, especially at the critical Mach number. A vehicle performance approximation was used, which is valid where it is needed (at 40,000ft+), where our aircraft will not be travelling greater than Mach 0.8, which will be below critical. We were asked to design for flight at well over critical Mach number, but this is not feasible. The aircraft is 220,000lbs, and has to open large cargo-bay doors at high speeds in order to launch the UCAV's. Given that we are designing for efficient, long-loiter flight conditions at subsonic speeds, our aircraft could not possibly push 220,000lbs of bulky, blunt body cargo jet well past the critical Mach number. Thus, we will fly at Mach 0.8 at a maximum. We compensate for this by launching the UCAV's with an initial, one-time use rocket thrust. Our Flight envelope is shown below in Figure 1.

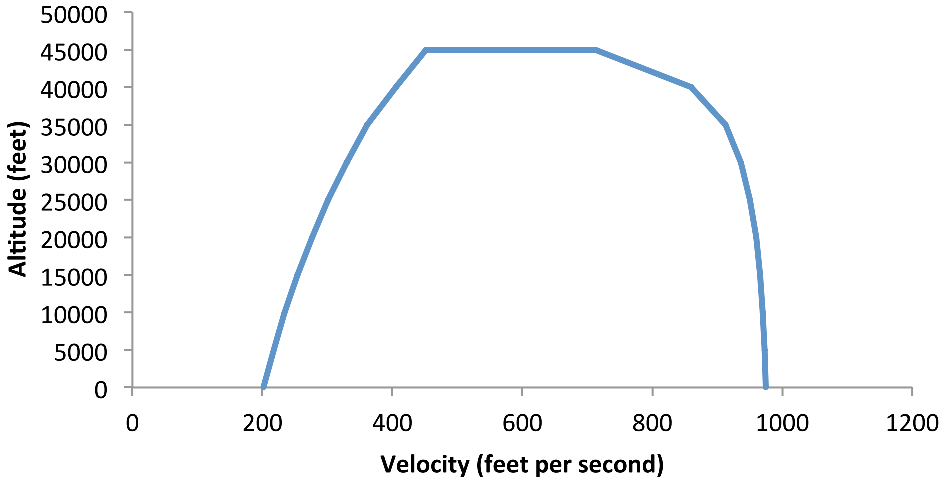


Figure 1 Flight envelope for the TPC

Unmanned Combat Aerial Vehicle (UCAV)

Each UCAV must carry four hypersonic weapons, found to be 750lbs each. The missiles were chosen to be placed close to the body under the wings. Our UCAV mission profile includes: take-off at 40,000ft at Mach 0.8 with full fuel, accelerate using detachable rocket thrusters to move through the transonic regime to Mach 2.0, climb between 20,000 and 90,000ft higher with RAMJET engine, accelerate to Mach 4.0, then either glide back to Earth or launch hypersonic missile(s). Our preliminary analysis involved weight-sizing, shape, and drag analysis. We used a TSFC of 4.1lb/lb*sec, an L/D of 7.5, and a calculated lift coefficient at cruise of 0.21 based on historical values. Rocket thruster analysis is excluded because they are small, one-time use boosters only used to push through the transonic regime. However, we will include our climb and acceleration analysis, which was used to size the aircraft. We took worst case-scenario (max climb needed) to size the aircraft. We assumed a climb time of 5 minutes, which involves a flight angle of just 8.62^{o} when traveling at Mach 2.0. We assumed a level acceleration after climb of 1.5g's ($48 ft/sec^2$) for 44.5 seconds to reach Mach 4.0. Using Bruguet's formula, we approximated the fuel fraction needed for 5 minutes of climb at Mach 2.0 and acceleration at 1.5 g's for 44.5sec (with acceleration TSFC of 8.2 due to increased efficiency at higher Mach). Our final fuel fraction came out to be ~16% of our gross weight. In order to carry our four missiles and fuel while keeping enough empty weight to withstand the conditions at supersonic flight, we estimated a GTOW for the UCAV at 8,500lbs. The density of Jet A fuel is 0.84 kg/L, using this we found our fuel volume and weight to be $7.219 ft^3$ and 500lbs respectively. To ease the passage through the transonic regime, we designed our UCAV shape to closely resemble a Sears-Haack body. We assumed a fuel volume fraction of 0.4 based on historical data for similar aircraft, giving us a total volume of $18.04626 ft^3$. We chose our length to be 25ft to fit well into the TPC (the C-130 has a cargo bay of ~9ftx10ftx55ft, which would allow us four UCAV's tightly packed). The corresponding R_{max} for a Sears-Haack body is 0.625ft, which yields a wave drag coefficient of 0.0277 (the ideal case). We decided such a small wing-span would be impractical while carrying missiles, so we increased the R_{max} to 2.5ft (a wingspan of 5ft). We cannot exactly calculate our transonic wave drag, but we know our lower-bound is

0.277, which is why we are using rockets. We chose a wing area of $70ft^2$ to bring down the wing loading to a reasonable value ($121.43lbs/ft^2$ for UCAV versus $136lbs/ft^2$ for the MiG-31 which flies at ~Mach 3). Transonic drag and Sears-Haack calculations shown below.

Table 2 Sears-Haack

	Sears-Haack	
Length	25	ft
Rmax	0.624558	ft
Span	1.249117	ft
Cd_Wave	0.027719	
Wing Area	70	ft^2
AR	0.02229	
	Actual	
Length	25	ft
Rmax	2.5	ft
Span	5	ft
AR	0.357143	
Wing Loading	121.4286	lbs/ft^2

Although in the transonic regime the wave drag is completely dominant, we considered the skin friction drag afterwards by use of Anderson's skin drag equation for compressible supersonic flow. At low flight (60,000ft), our C_f came out to be ~0.0015, and at high flight our C_f came out to be 0.0043. Skin friction calculations shown below. Two values are given where values diverge for high and low altitude.

Table 3 Skin friction calculations

	Value	Units
V	3872.3	fps
	4299.3	fps
rho	0.00023	slugs/ft^3
	0.0000037	
mu	3.51E-07	lb*s/ft^2
	2.97E-07	
length	25	ft
Tstar/Tinf = 1+.1198*M^2	2.92	
Re=rho*v*l/m	62,314,205	60000ft
	1,339,463.6	150000ft
minf/mstar	0.006	
	0.005	
Cf	0.0015455	
	0.0043094	

Our wave drag was approximated using supersonic slender wing theory. We found our wave drag coefficient to be ~0.011. We used a supersonic drag estimation technique found online[1]. Induced drag for our aircraft at Mach 4.0 was found to be approximately 0.039.

Our UCAV's pitching moment can be approximated with the following equation:

Equation 1 Supersonic Pitching Moment

$$C_{m,\frac{1}{2}c,j} = -\frac{4\alpha_j}{\sqrt{M_{\infty,j}^2 - 1}}\left(\frac{1}{2} - \frac{x_0}{c}\right) + \frac{4\alpha_j}{\sqrt{M_{\infty,j}^2 - 1}}\int_0^1 \left(\frac{dy_c}{dx}\right)\frac{x - x_0}{c}\,d\left(\frac{x}{c}\right)$$

For our aircraft, the pitching moment coefficients were found to be on the order of 0.004. Our control surfaces will include two very small vertical tails in the back, and two very small elevators in the back.

To simplify our calculations, we assumed a constant rate of climb at Mach 2.0 and 8.63^o pitch attitude (300 ft/sec ROC).

As per instructions, our aircraft can pull 15G's in coordinated turns. This is done through composite materials. Using goal seek analysis in MS Excel (centripetal acceleration versus maximum G's), we calculated the minimum turn radius at Mach 4.0 to be 31,000ft at low altitude and 38,000ft at high altitude. This means a full 180^o turn takes anywhere from 25 to 27 seconds at least.

Hypersonic Weapon (JAMRAAM)

The analysis of our hypersonic weapon, the Jet Actuated Medium Range Air-to-Air Missile (JAMRAAM), included Newtonian Aerodynamic lift-drag analysis, mission profile, and weight-sizing analysis. Our initial weight estimate was chosen at 750lbs based on historical data and the fact that it should weigh considerably less than a THAAD-class ICBM (2000lbs) since it is launch at high atmosphere at Mach 4.0. The warhead occupied 40kg, or 88lbs, of our missile.

Newtonian aerodynamic analysis was performed at a pitch attitude of 20^{o}. We found our pressure coefficient to be 0.233 assuming no stagnation pressure losses. We chose the diameter of the missile to be 1.5ft to reduce drag (already quite small at operating altitudes) and based on the THAAD's diameter of 1.2ft. Depending on whether the missile is operating at 60,000ft or 250,000ft, the drag on the missile can vary from 57.94lbs to 0.014lbs. Since our missile operates in such high-altitude conditions, we assumed the drag to be negligible in our fuel expenditure calculations, instead looking at acceleration and range from rocket equations. Although it is rocket powered, it is an air-breathing rocket of the SCRAMJET class. A comparison between the raw THAAD class rocket data and our hypersonic weapon can be seen below.

Table 4 Comparison of hypersonic weapon and THAAD rocket

	Steady State Mach 8	THAAD	
Final Mass	80	8	lbs
ISP	300	300	sec
Initial mass	750	2000	lbs
Diameter	1.5	1.21	ft
Area	1.77	1.15	ft^2
C_p	0.23	0.23	
theta	0.35	0.35	
rho	0.00022	~0	slugs/ft^3
	0.000000056		
a	968.08	~0	fps
	939.96		
Q	0.97	~0	psi
	0.00023		psi
Drag	57.94	~0	lbs
	0.013737		lbs
V_{eq}	9655.51	9655.51	fps
Range	~525000	>650000	ft
Ceiling	250000	492000	ft
Speed	7744.61	2800	fps
	7519.71		
Reaction Time	2	2	min

Conclusion

As a conclusion we present our findings for worst case scenario response of the TPC/UCAV/JAMRAAM system in terms of response time and range. Worst case scenario defined as maximum climb for each stage (60,000ft to 150,000ft to 250,000ft).

Table 5 Mission profile results

	Worst Case Scenario					
		Mach	**Time (min)**	**a (fps)**	**Distance (ft)**	**Distance (mi)**
TPC	Launch	0.8	3	995	143232	27.13
UCAV	Climb	2	2	968	229478	43.46
	Accelerate	2-4	0.5	995	74600	14.13
	Cruise	4	4	968	929353	176.01
JAMRAAM	Accelerate	4-8	0.5	968	174254	33.00
	Climb	8	1	1057	358864	67.97
				Response	11	min
				Range	334.57	miles

For the purpose of maximizing range to response time, we decided the UCAV would supercruise for four minutes before launching the JAMRAAM. As shown above, our three stage missile defense system has an effective response radius of 334.57 miles and 11 minutes. This is considerably further than the 125+ mile range of THAAD class missiles, although 11 minutes is a sizeable window for an ICBM to slip by, according to online estimates it would take on the order of thirty minutes for an ICBM to travel over the north pole from Russia to the United States. Therefore, this missile defense system could be quite effective if warnings could be generated within twenty minutes of ICBM launch from Russia (or more time from China). Our preliminary analysis of the three-stage missile defense system puts it well ahead of its competitor, the THAAD class missile defense.

However, whatever re-usability and flexibility gained from the UCAV stage's gliding capabilities in the event of an abort is lost in the massive operational and acquisition costs involved in the 220,000lb transonic patrol crafts that would have to be kept airborne at any given time on both American seaboards. Also, the technology for effective RAMJET and SCRAMJET engines is still relatively recent and proprietary, making some of the values for engine performance mere approximations based on experimental demonstrations.

This analysis was performed assuming a relatively shallow trajectory from the ICBM so that we can hit it at the edge of the atmosphere, several hundred miles from the USA. In the event that it arrives at a deeper trajectory, over the United States, we would need much more forewarning for this system to work. The JAMRAAM cannot operate at low altitude, and is designed to rise to the target rather than dive with it. Furthermore, the JAMRAAM is designed to kinetic/explosive kill, which could potentially initiate the warhead in question, raining radiation/shrapnel on US soil. This defense system is therefore best used on shallow trajectory, distance ICBM's. Otherwise, the ICBM will detonate over US soil or completely avoid the JAMRAAM because it is outside design specs. The UCAV could potentially attempt a kinetic kill since it can operate at lower altitudes, but it cannot travel nearly as fast as the JAMRAAM.

So, if each stage could be developed and coordinated properly to work together, this three-stage missile defense system could be a rather large improvement on the current THAAD class missile defense system. However, integration of this kind of technology on such a large scale would be a massive undertaking, involving billions of dollars of tax payers' money for a defense system that would have to be kept airborne at all times during periods of global unrest. This is perhaps less feasible than the engineering difficulties of the project. Also, the difficulties in structural analyses of the TPC during UCAV launch and the UCAV during 15G coordinated turns alone could keep FAA busy for decades. In conclusion, this project, though aerodynamically feasible, is large enough economic and time commitment that it would be unlikely to be implemented given current technology.

References

[1] http://www.desktop.aero/appliedaero/compress3d/ssdragest.html