AURORA

Aerial
Unmanned
Remote
Operated
Rescue
Aircraft

Executive Summary

29 MAY 2016

Nanjing University of Aeronautics and Astronautics

Undergraduate Design Report Executive Summary

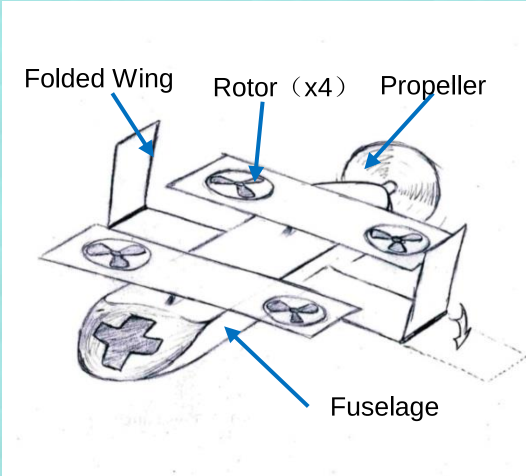
Mission Requirements

In response to the Design Competition sponsored by Bell Helicopter, the aim of NUAA Undergraduate Team is to design an unmanned aerial vehicle (UAV) that meets the following requirements.

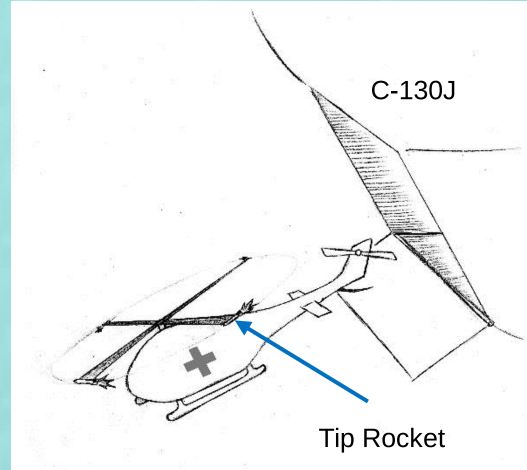
Items	Units	Required Values	Designed Values	Design Compliance
1、Payload of UAV				
Weight requirement	lb	500	557	√
Size limit (Qty. 18)	$inch^3$	16’’ x 11’’x 9’’		√
2、Sizing & Payload of C-130J				
Cabin limit				
Length	ft	40		√
Width	inch	119		√
Height	ft	9		√
Cabin door limit				
Length	inch	123		√
Width	inch	119		√
Payload limit	lb	34,000		√
3、Air drop of UAV				
C-130J flight conditions				
Altitude	ft	15,000		√
Velocity	knot	140		√
Man assist		Yes	Yes	√
4、Autonomous flight of UAV				
Altitude requirement	ft	⩾1,000	11,000	√
5、Hover performance of UAV				
Altitude requirement	ft	10,050	10,050	√
Above ground	ft	50	50	√
6、Cargos drop from UAV				
Time limit	min	⩽1	1	√
Velocity limit	ft/sec	⩽5	5	√
Accuracy requirement	ft	10	8	√
7、Range from drop zone to base	nm	⩾50	60	√

DZ is referred to the disaster zone.

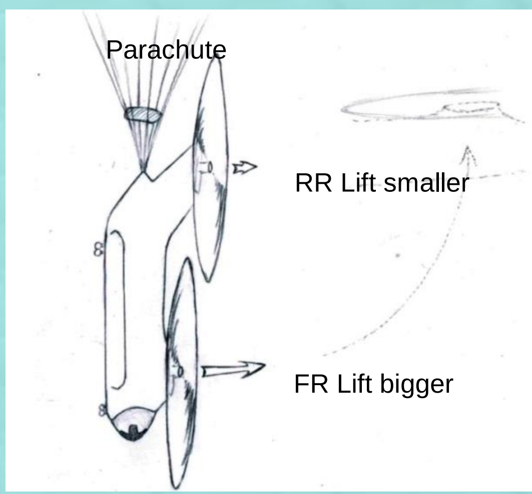
Design Concepts



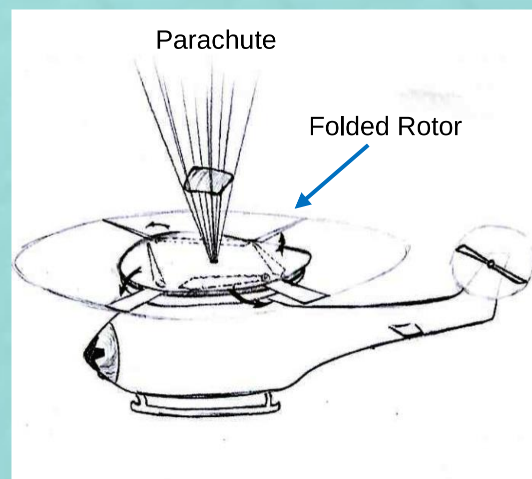
Concept 1：Concept of Quadrotor



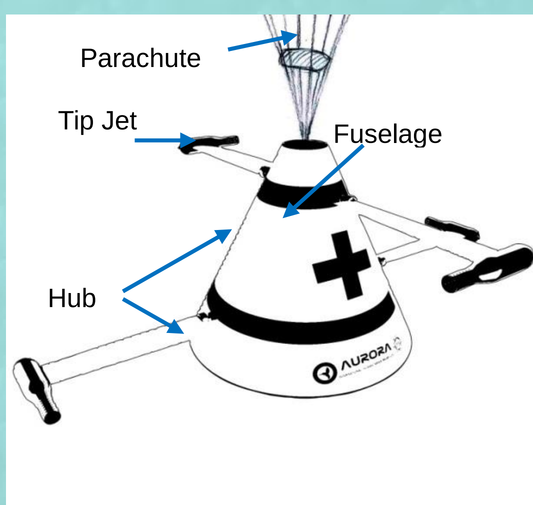
Concept 2 ：Concept of TRSMR



Concept 3：Concept of Tandem



Concept 4：Concept of FBSMR



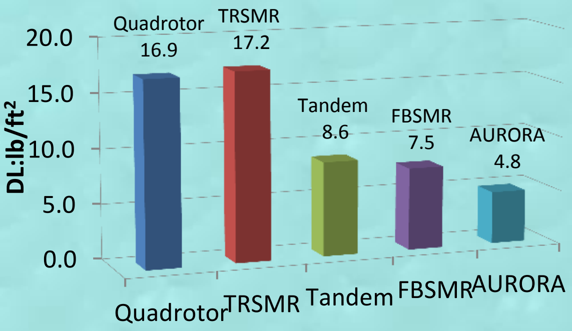
Concept 5：Concept of AURORA

Five candidates of the initial concepts were presented by the team brainstormed according to the RFP.

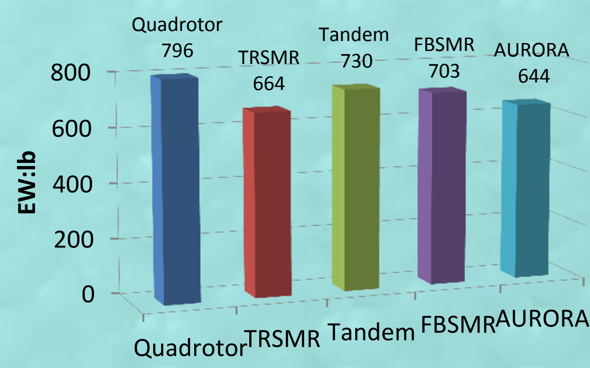
All these concepts are based on the idea that propulsion starts out of the C-130J after departing from the aircraft cabin.

The idea that propulsion starts in C-130J before departing from the transport aircraft is eventually eliminated after carefully design considerations.

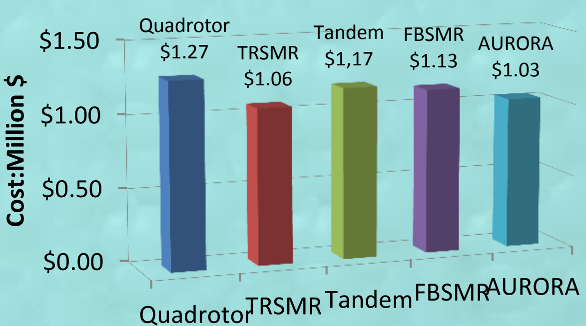
UAV Design Parameter Comparisons



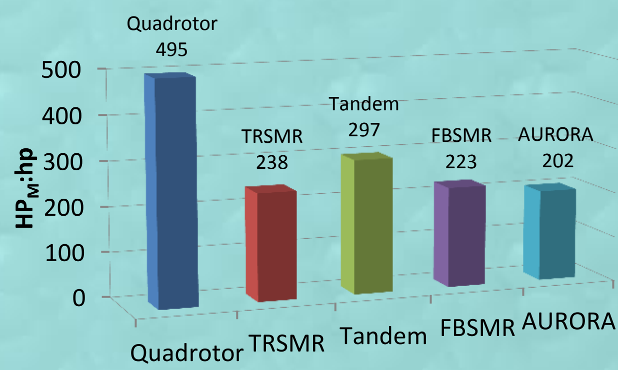
（a）**Disc Loading(DL) Estimate**



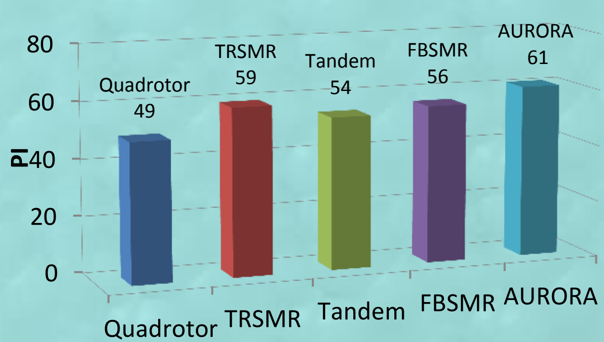
（b）**Empty Weight Estimate**



（c）**Non-Recurring Cost Estimate**



（d）**Required Power Estimate**



（e）**Productivity Index (PI) Estimate**

Comparisons in five important parameters among the five candidates are shown here.

AURORA has the lowest DL, lowest empty weight, lowest cost, lowest required power and highest Productivity Index among the five UAV candidates.

Feasibility Trade-Off Decision Matrixes of 5 UAV Candidates

WHATS \ HOWS				Importance	Configurations: Non-Parachute		Configurations: Parachute		
					Quadrotor	TRSMR	Tandem	FBSMR	AURORA
System Effectiveness	Availability & Dependability	Operability	Operator Crew Size	9	○	○	○	○	○
			Mission Control System	10	○	○	○	○	○
		Maintainability	MTTR	9	△	○	◎	◎	◎
			MMH/FH	9	△	○	◎	◎	◎
		Reliability	Endurance	9	○	◎	○	○	◎
			Transportability	9	○	△	◎	△	○
			MTBF	7	△	○	○	○	◎
		Mission Frequency	Peacetime Training	9	○	○	○	○	○
			Emergency Deployment	7	△	○	○	◎	◎
		System Safety	Autorotation	7	○	◎	○	○	◎
			Blade Frequencies	7	○	◎	○	○	◎
			Start Up/Shut Down	7	○	◎	○	◎	◎
			Crashworthiness	9	△	○	△	◎	◎
		Vulnerability	Tip Speed	9	○	○	○	○	◎
			Size	7	△	△	○	○	◎
		Recyclability	Material Reuse	9	△	○	△	◎	◎
	Capability	Performance	10050ft Hovering	10	○	○	△	○	◎
			>11000ft Auto Flight	10	◎	◎	○	○	○
			PL Delivery Veracity	9	○	○	○	○	○
			PL Delivery Velocity	10	○	○	○	○	○
			>50 nm Range	10	○	◎	◎	◎	○
			Handling Qualities	8	◎	○	○	○	○
		Environment	<15 Disk Loading	9	◎	△	○	△	○
Cost Effectiveness	Production	R&D	Process	7	△	○	○	○	○
		Manufacturing	Equipment	7	△	○	△	◎	○
			Labor Time/Complexity	8	△	○	△	○	○
			Material Type	8	○	○	○	○	○
			Quality Control	6	△	○	△	○	○
	Operating	DOC	Reserves	9	○	○	◎	○	○
			Maintenance	8	△	○	△	○	◎
			Fuel, Oil& Lubricants	7	○	○	○	○	○
△ Weak (1)		Organization Difficulty			4	4	2	3	2
○ Medium (3)		Absolute Importance			753	1,027	939	1,143	1,461
◎ Strong (9)		Relative Importance			14%	19%	18%	21%	27%

By using the Quality Function Deployment (QFD) analysis, the AURORA concept scores the highest evaluation points. Therefore, it is down selected for the NUAA Student Design Competition (SDC) proposed candidate.

Mission Profile

Segment	Air Transport	Air Drop	Blades Deployment	Parachute Separation	Payload Delivery	Home Base Flight	Segment
Altitude	15,000 ft			>11,000 ft	10,050 ft		4,000 ft
Distance	0 nm	1 nm	1 nm	3 nm	1 nm	50 nm	
Time	0 min	1 min	1 min	2 min	1 min	60 min	3 min
Weight	PMGW	PMGW	PMGW	PMGW	Payload Expanded		

1. Ground Transport

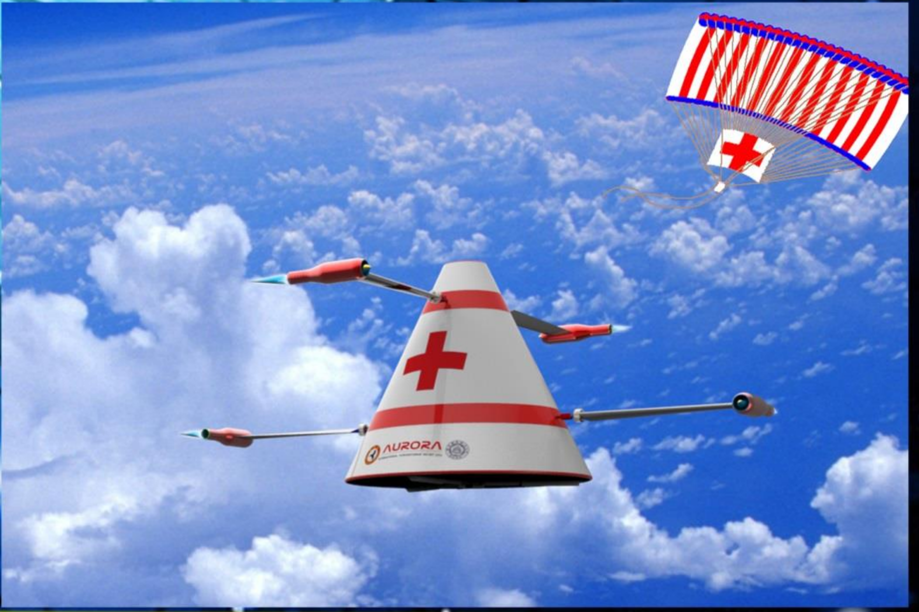
2. Air Transport

3. Air Drop

AURORA

Mission Process Sketch

4. Blade Deployment

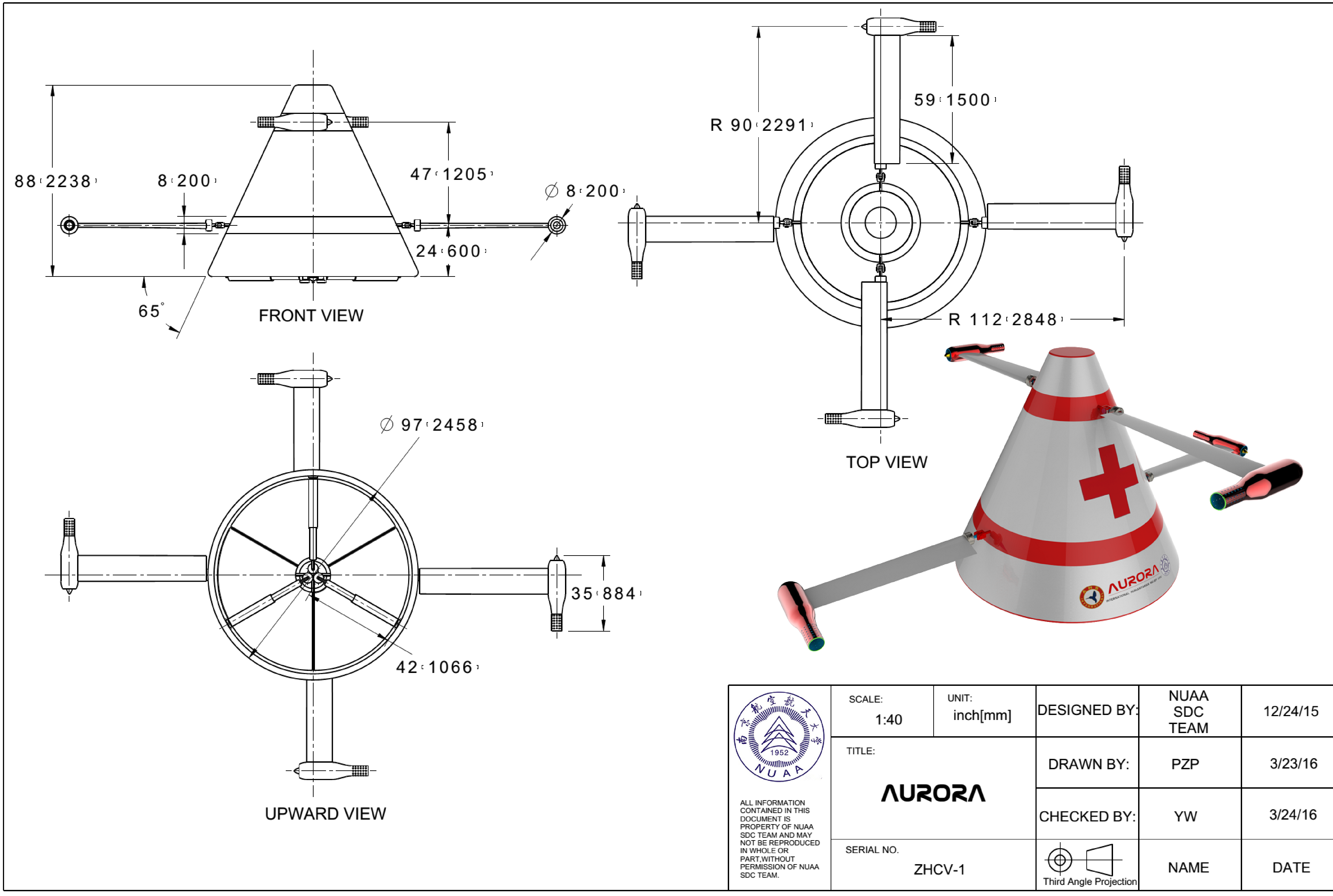


5. Parachute Separation

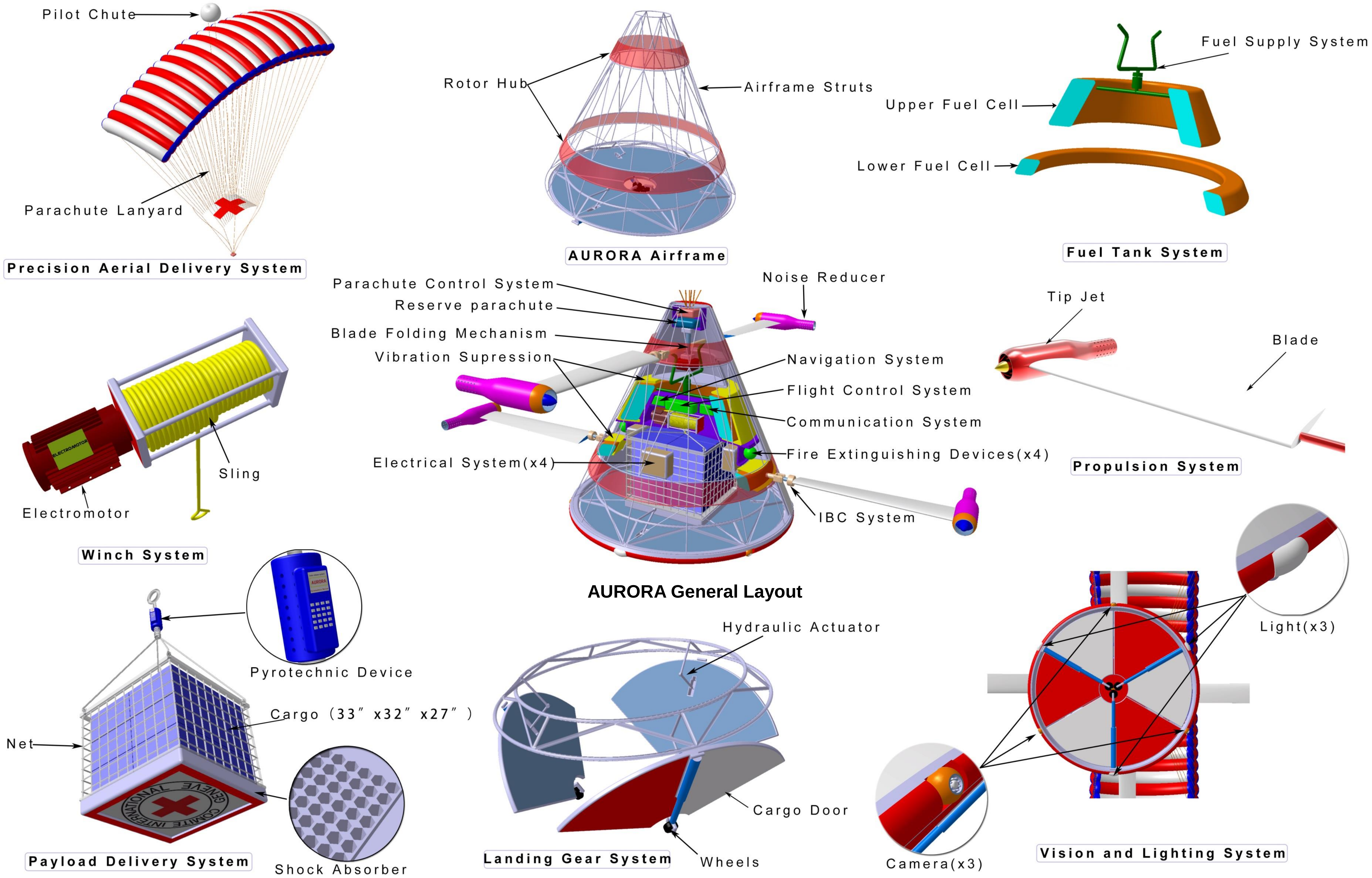
6. DZ Payload Delivery

7. Home Base Flight

8. Home Base Landing



Three View Drawing of AURORA



Pilot Chute
Parachute Lanyard
Precision Aerial Delivery System
Rotor Hub
Airframe Struts
AURORA Airframe
Fuel Supply System
Upper Fuel Cell
Lower Fuel Cell
Fuel Tank System
Parachute Control System
Reserve parachute
Blade Folding Mechanism
Vibration Supression
Noise Reducer
Navigation System
Flight Control System
Communication System
Fire Extinguishing Devices(x4)
Electrical System(x4)
IBC System
Tip Jet
Blade
Propulsion System
ELECTROMOTOR
Sling
Electromotor
Winch System
AURORA General Layout
AURORA
Pyrotechnic Device
Cargo (33″ x32″ x27″)
Net
COMITE INTERNATIONAL GENEVE
Shock Absorber
Payload Delivery System
Hydraulic Actuator
Cargo Door
Wheels
Landing Gear System
Light(x3)
Camera(x3)
Vision and Lighting System

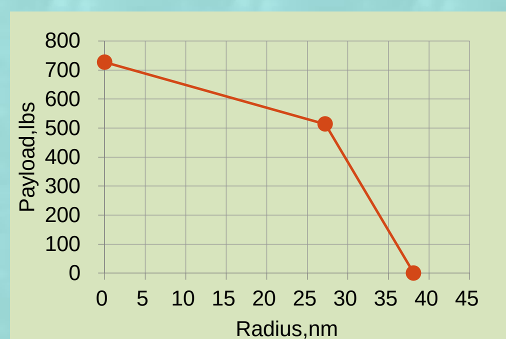
AURORA Characteristics Overview

Items	Units	Values	
Weight Empty	lb	726.90	
Fuel Weight	lb	213.7	
Payload	lb	557.30	
Gross Weight	lb	1,498	
Height	ft	88.00	
Width	ft	97.00	
Rotor System		Upper Rotor	Lower Rotor
Blade Length	ft	4.92	4.92
Radius	ft	7.19	9.01
Chord	ft	0.99	0.99
Number of Blade		2	2
Solidarity		0.07	0.05
Tip Speed	ft/s	750.00	750.00
Disc Loading	lb/ft^2	5.20	3.84
Propulsion System		Tip Jet	
Quantity		4	
Static HP	HP	46.00	
tatic SFC	lb/ (lb·hr）	3.18	
Forward Flignt SFC	lb/ (lb·hr）	2.07	

Performance Overview

Items	Units	Values
Max Forward Speed	kt	77.62
Max Range Speed	kt	53.92
Max Climb Rate	ft/s	57.19
Range	nm	60
Endurance	min	66.77

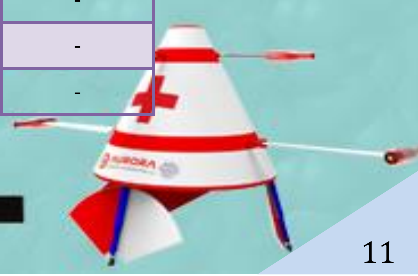
Payload Range Curve



This is the performance overview of AURORA. These two charts are general parameters, propulsion parameters, rotor parameters and forward flight performance. They are chosen deliberately to meet the requirements in hover state and request for range. What's more, the AURORA UAV is capable of carrying 550 lbs of water bottles, which is 10% more than RFP. The payload range curve is also given in this page.

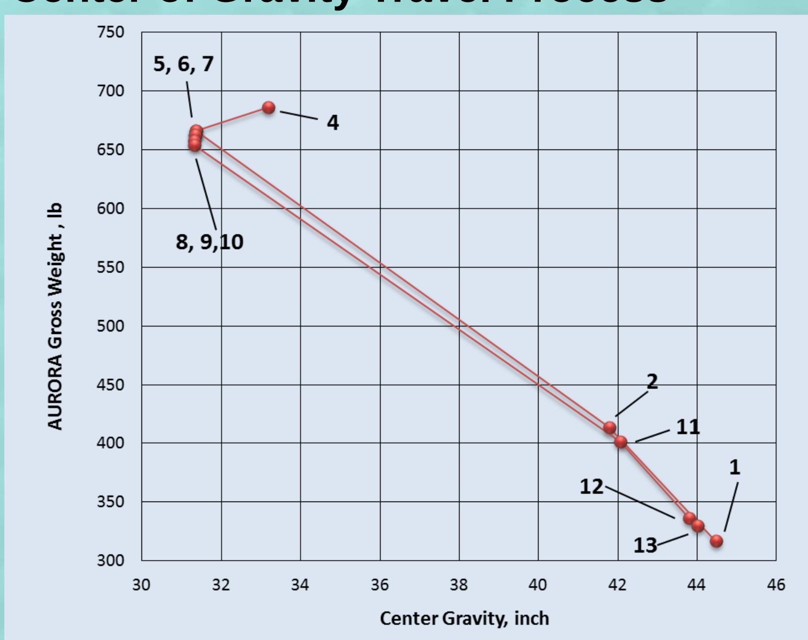
Total Weight and CG Position Calculations

Group	Values(lb)		Rate of EW(%)	Rate of GW(%)	Fuselage Station(in.)	Moment (in. lbs)
Rotor Group		83	11.54	5.58	47.3	3,938
Up Rotor	36		5.01	2.42		-
Down Rotor	36		5.01	2.42		-
Folding Mechanism	4		0.61	0.30		-
Hinges	2		0.31	0.15		-
Bearings	4		0.61	0.30		-
Body		209	29.04	14.03	35.4	7,414
Truss	132		18.34	8.86		-
Skin	33		4.59	2.22		-
Compartment	44		6.11	2.95		-
Landing System		51	7.03	3.40	3.9	199
Landing Gear	33		4.59	2.22		-
Retractile System	13		1.83	0.89		-
Brake System	4		0.61	0.30		-
Power System		174	24.19	11.69	47.3	8,252
Engine	127		17.62	8.51		-
Engine Control System	2		0.31	0.15		-
Starting System	1		0.15	0.07		-
Rotor Brake System	2		0.31	0.15		-
Lubrication System	17		2.29	1.11		-
Fuel System	20		2.75	1.33		-
Drive System	6		0.76	0.37		-
Auxiliary Power System		35	4.89	2.36	51.2	1,804
Batteries	33		4.59	2.22		-
Starter Generator	2		0.31	0.15		-
Electrical System		37	5.20	2.51	55.1	2,064
Lighting System	2		0.31	0.15		-
Camera Device	9		1.22	0.59		-
Cable& Wire	4		0.61	0.30		-
Dipping Device	22		3.06	1.48		-
Avionics system		67	9.25	4.47	74.8	4,984
Flight Control System	45		6.19	2.99		-
Communication System	4		0.61	0.30		-
Navigation System	11		1.53	0.74		-



Group	Values(lb)		Rate of EW(%)	Rate of GW(%)	Fuselage Station(in.)	Moment (in. lbs)
Other Assistive Devices	7		0.92	0.44		-
Interior Equipment		35	4.89	2.36	59.1	2,081
Fire Extinguishing System	11		1.53	0.74		-
Vibration Suppression	17		2.29	1.11		-
Spare Parachute	8		1.07	0.52		-
Anti-Icing Group		7	0.92	0.44	55.1	364
Instruments Group		2	0.31	0.15	63.0	139
Contingency		20	2.75	1.33	37.4	741
Total Empty Weight		721	100.00	48.31	Total Moment of EW	31,981
Maximum Usable Fuel		214		14.32	33.1	7,066
Payload		557		37.36	14.3	7,964
Mission Payload	551			36.92		-
Mission Equipment Package	7			0.44		-
Designed Gross Weight		1492		100.00	Total Moment of GW	47,011
Parachute	44				2.95	94.5
$C.G.pos._{empty} = \frac{31,981.04}{720.59} = 44.38$ fuselage station				$C.G.pos._{total} = \frac{47,010.78}{1,491.52} = 31.52$ fuselage station		

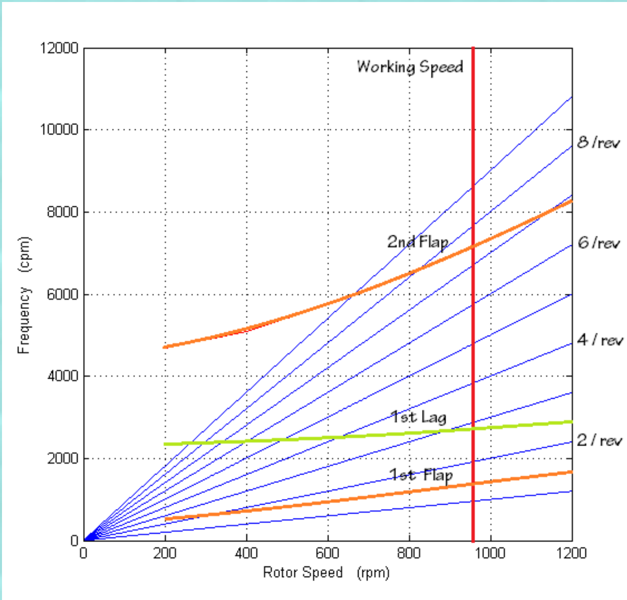
Center of Gravity Travel Process



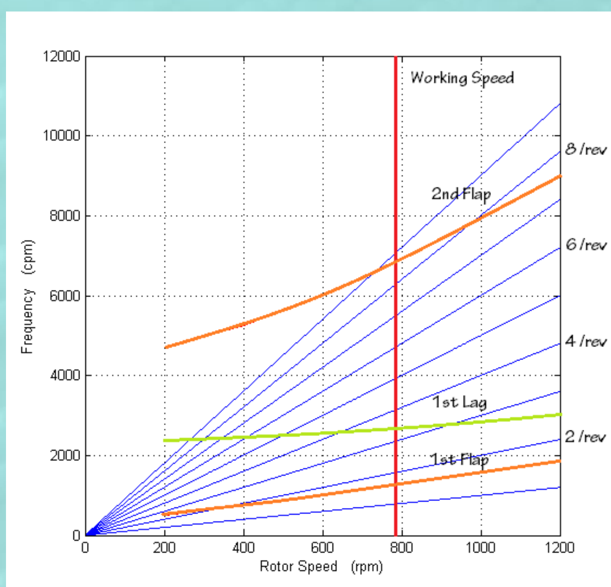
Main Process of the Mission Cycle:

1. Empty Weight
2. Adding Fuel
3. Adding Payload
4. Adding Parachute
5. Shoot Out the Parachute
6. Unfold the Parachute
7. Starting Engine
8. Release the Parachute
9. Autonomous Control
10. Hovering Phase
11. Release Payload
12. Flight to Base
13. Landing

Blade Rotational Frequency Fan Plot



Fan Plot of the Upper Rotor

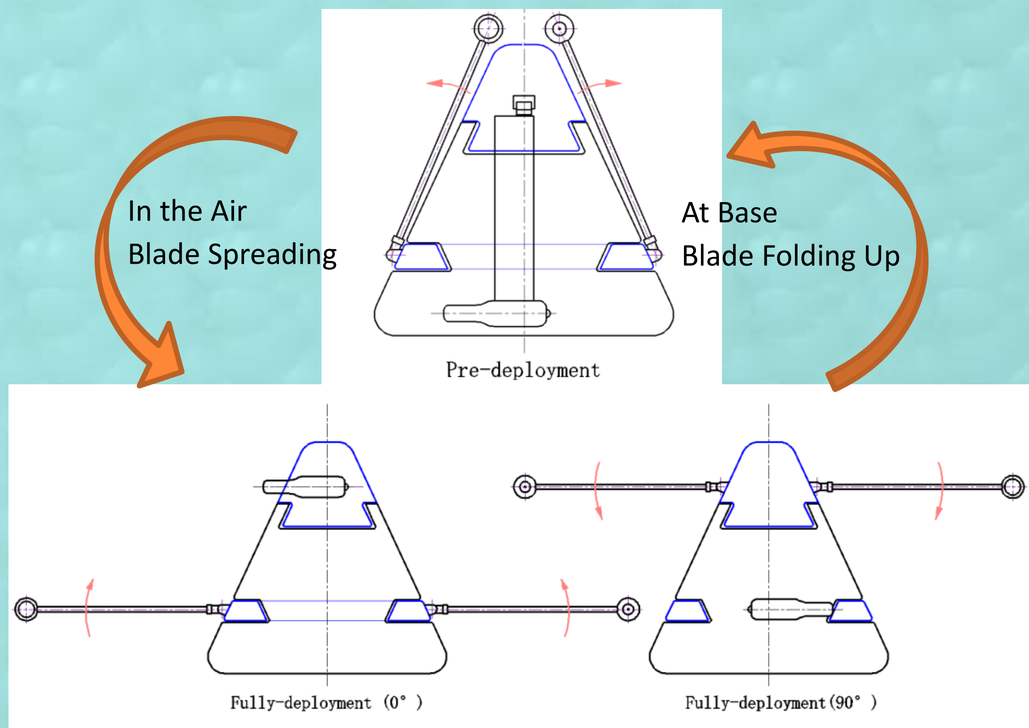


Fan Plot of the Lower Rotor

The Myklestad Method was used to calculate the natural frequency of the blades. The blade was divided into a 20 point mass. It's easy to find that the two adjacent points have a close connection. And the boundary conditions are known to us, in which case the root of blade is clamped and the tip of the blade is free. The MATLAB program can be built based on above conditions to obtain the flap and lag frequency of the blade. Then, the fan plot can be drawn. Figures on the left respectively show the upper rotor blade's fan plot and lower's fan plot. As shown in these two figures, when the upper and lower rotors rotate in working speed, blade resonance will not occur.

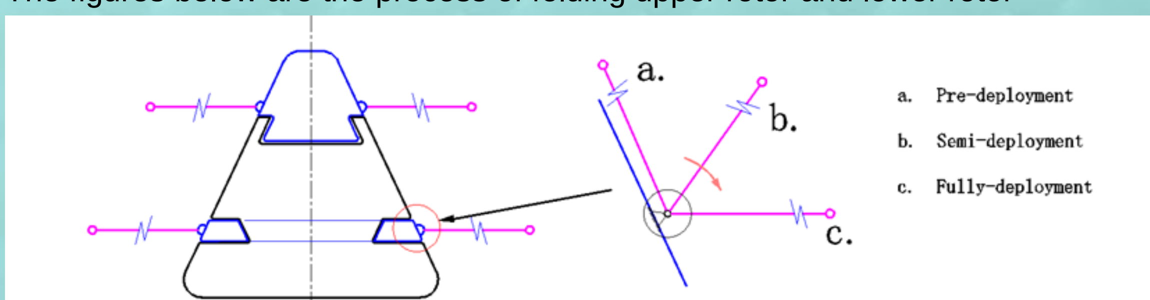
Folding Blades

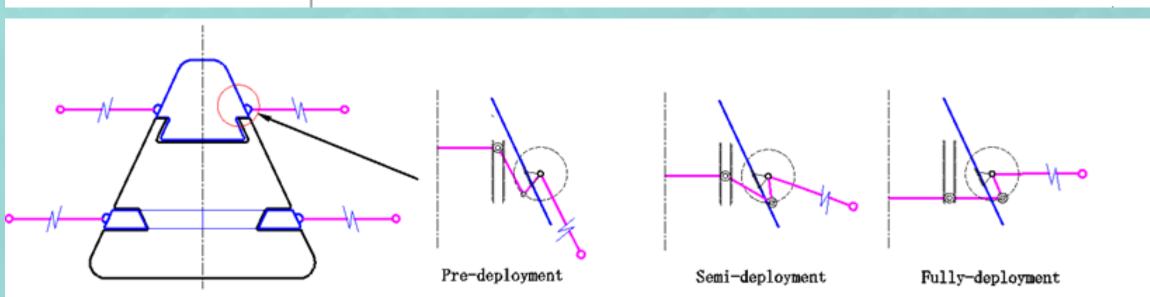
Due to the C-130J cabin space constraint, the four blades of the UAV are folded up and down as the below figures show. After the UAV is airdropped from the cabin, the blades will be spread out to the horizontal position and start to rotate. Once the UAV returns to the base and lands on the ground, the blades will be folded up and down to the original position for future missions.



Rotor Folding Mechanism

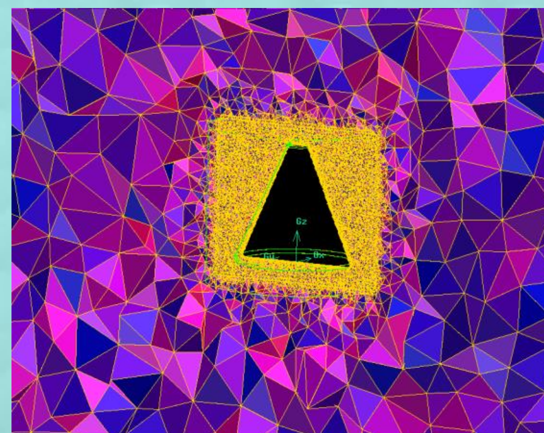
The figures below are the process of folding upper rotor and lower rotor



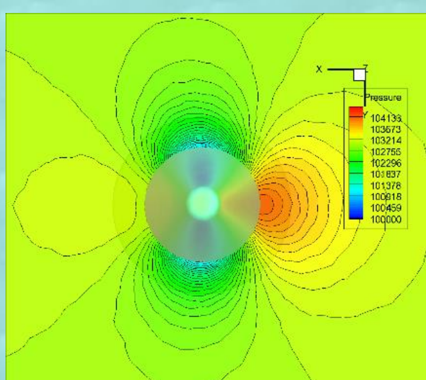


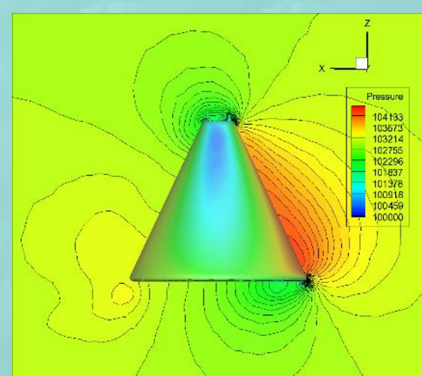
CFD of Fuselage

Mesh the separate fuselage with unstructured mesh by CFD pre-processing software GAMBIT. The computation domain is divided into two parts. The part close to the wall of fuselage is divided into smaller and more grids than the outer one so that the calculating precision will be great.

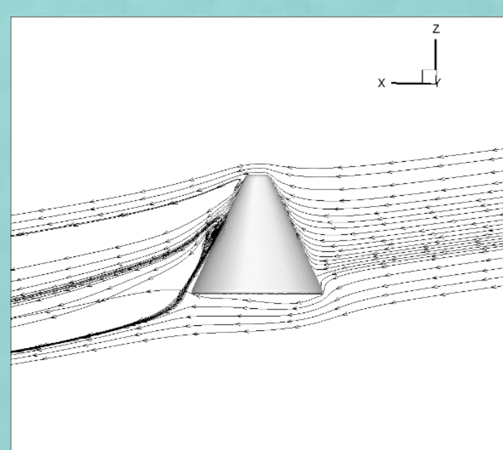


After the calculation in software FLUENT, contour of pressure in cruising flight are obtained. In the leeward side of fuselage, the pressure is smaller than the windward side. At the point where the flow is perpendicular to the wall, the pressure is the maximum.



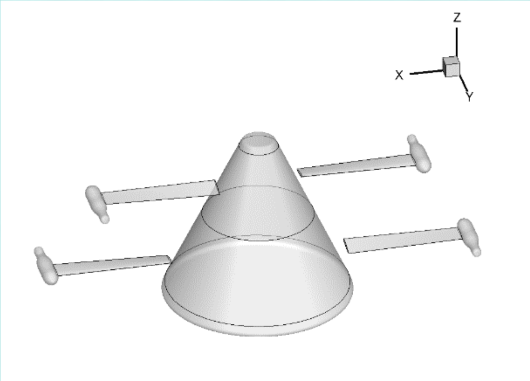


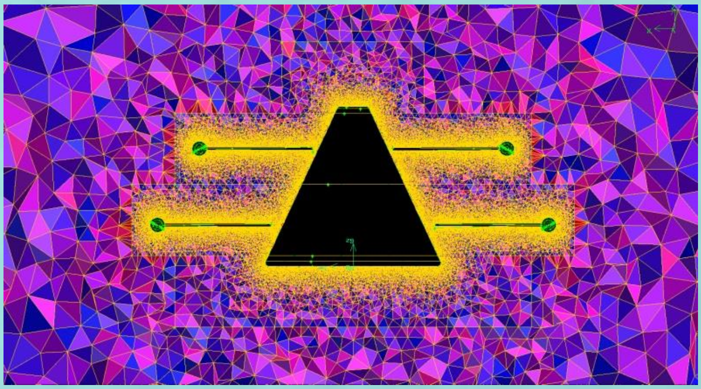
The flow streamlines on the symmetry plane of the fuselage are shown in figure. The angle of attack is 10°. The fuselage is not streamlined, as a result, the drag is quite big and the lift the fuselage provides is small.



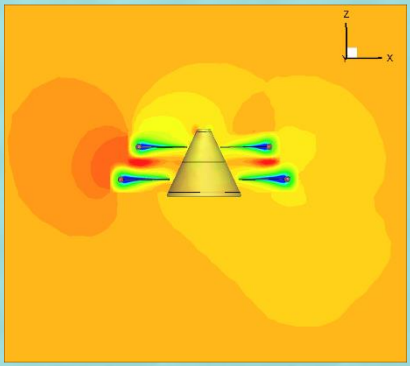
CFD of AURORA

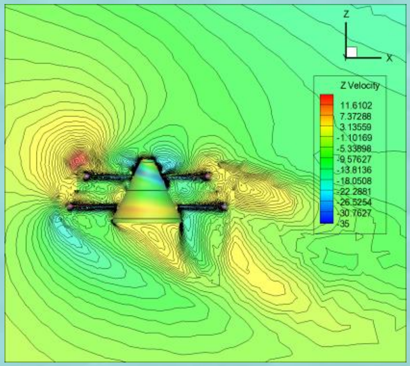
While the fuselage is added to four blades, the model is different and the structure of mesh dividing is also different. The advancing-front method is used to generate unstructured grids of high quality. Blades are:

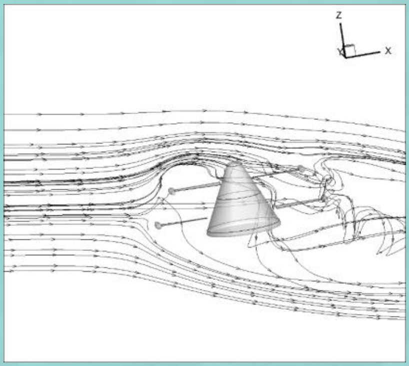


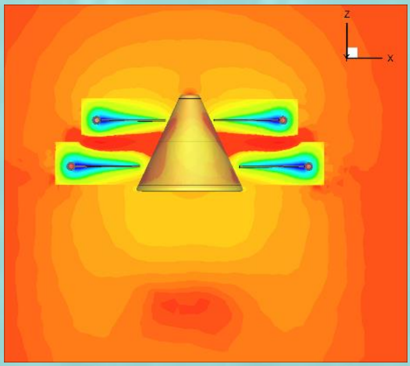


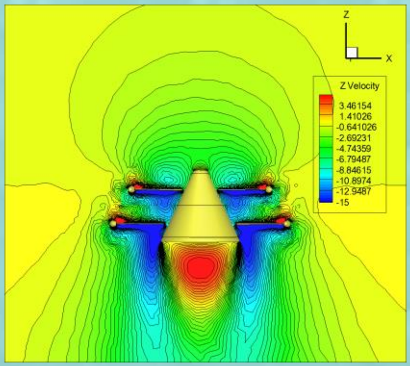
Also, the aerodynamic characteristics could be obtained. The upper three figures are contour of pressure, velocity in the vertical Z direction and flow streamline in cruising flight respectively. The lower three figures are aerodynamic characteristics in hover. In the figure describing the velocity in the vertical Z direction, the flow field around the lower rotors is affected by the upper rotor. In hover, at the bottom of fuselage there exists upward flow.

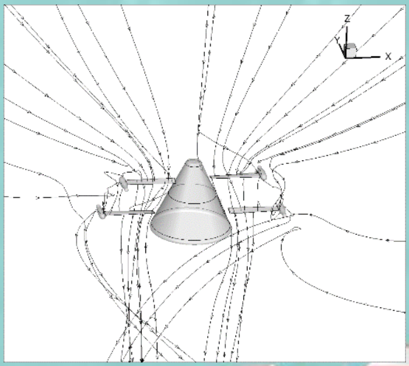




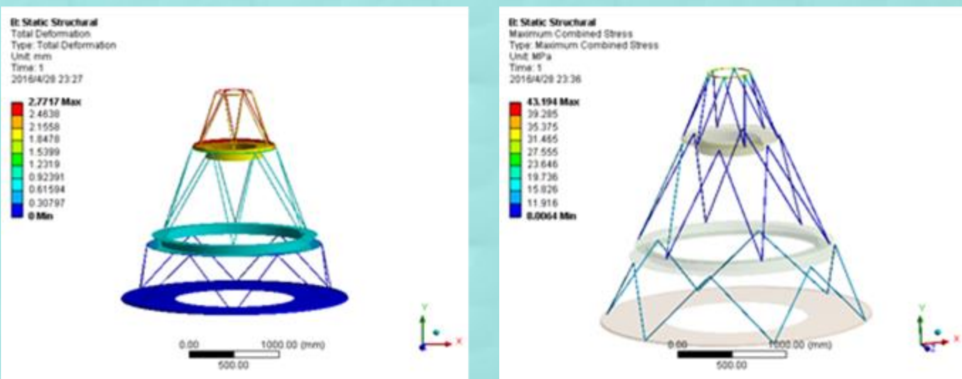






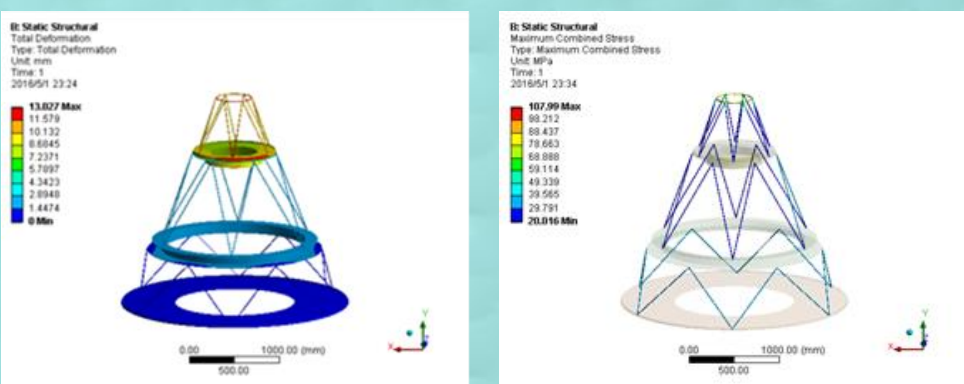


Structural Analysis



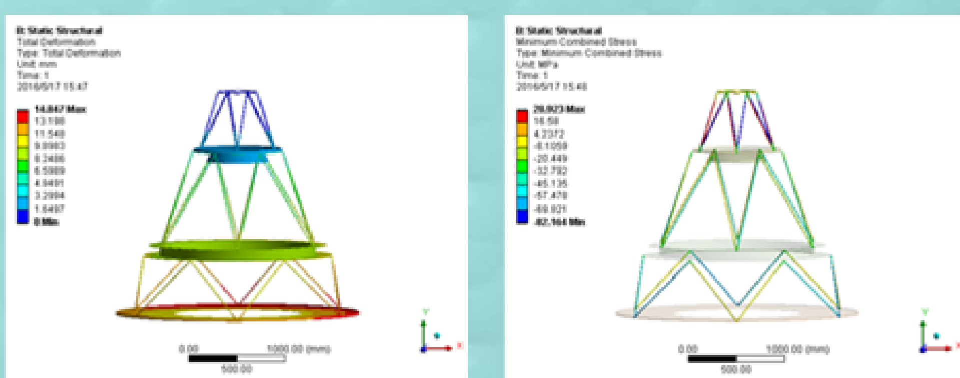
The Stress Check of Straight Flight Process

During the process of straight flight, the aircraft mainly encounters lift, gravity and air resistances. Maximum stress is 6,260 psi, less than the yield strength of material allowable.



The Stress Check of Deployment and Descent Process

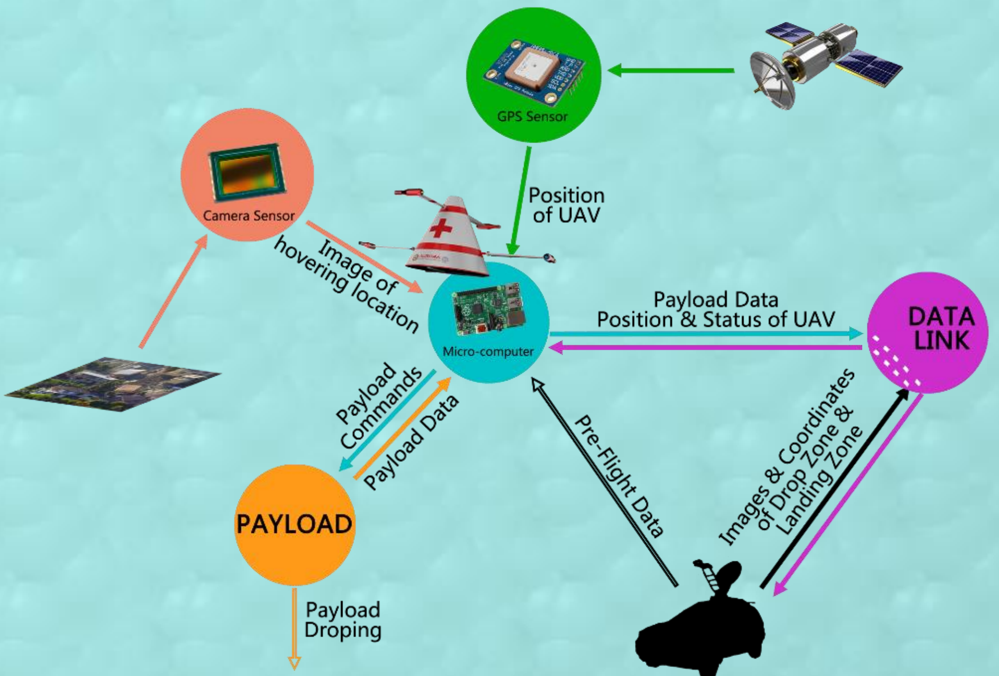
On the descend process, the dangerous mission profile is the parachute openned in an instant, the top suffer a huge impact load. Maximum stress is 15,600 psi, less than the yield strength of material allowable.



The Stress Check of Take-off and Landing Process

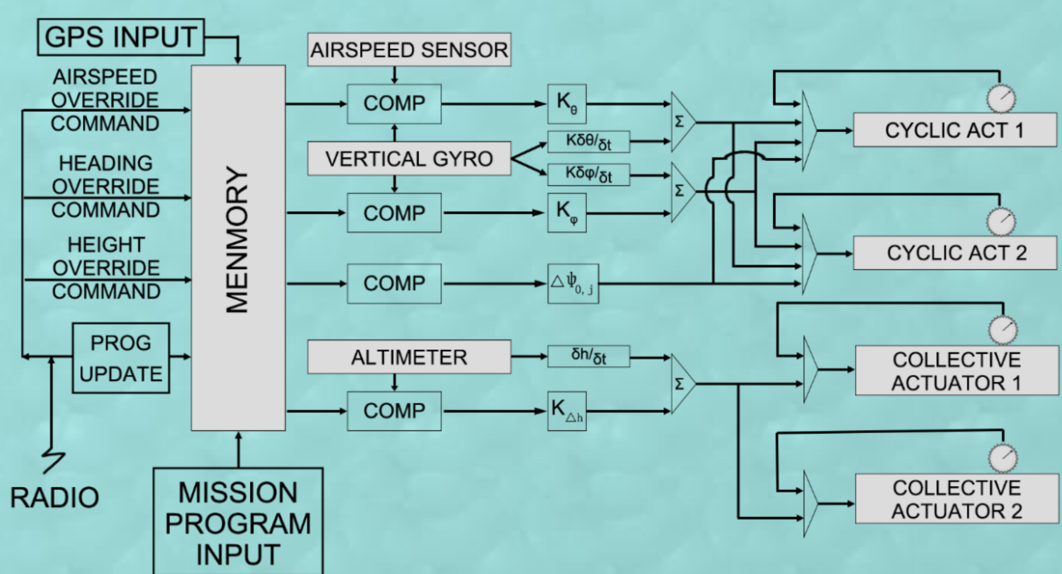
When landing, the aircraft's load mainly comes from the reaction force of the gear wheel, often referred to as "tire load". The maximum stress is -11,900 psi, less than the yield strength of material allowable.

Flight Control

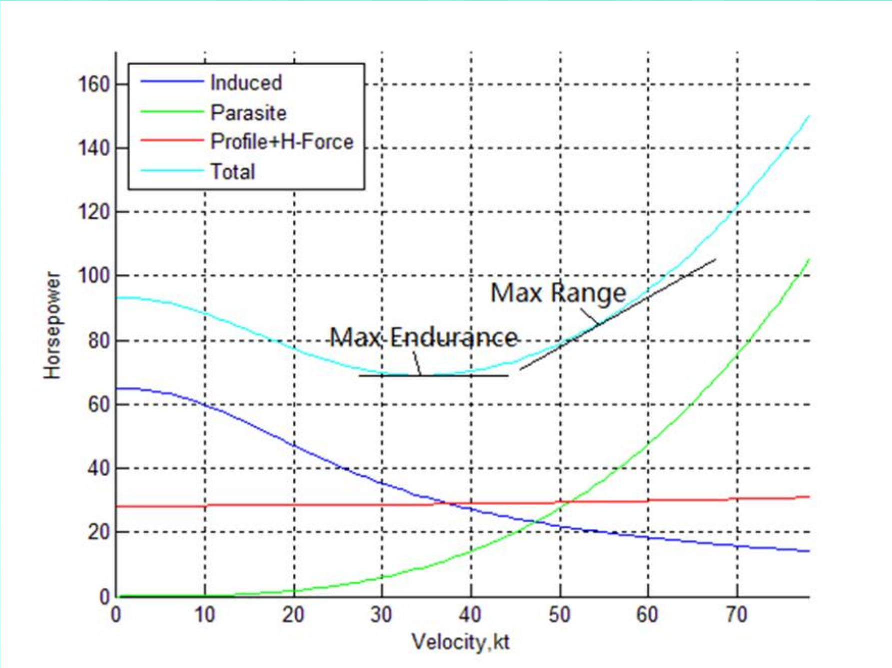


Micro-computer is the most important part of AURORA which connects GPS, camera sensor, payload system and command car. Between center command car and micro-computer, a data link is established to transfer data to modify the flight status on the pre-flight data from command car.

The Schematic of AFCS (Automatic Flight Control System) shows the relationship between commands, sensors and actuators. A memory part is required to store data and commands from the command car via radio and for computers to extract from. The number 1 represents upper rotor and 2 represents lower rotor, which indicates that AURORA's rotors are controlled respectively.

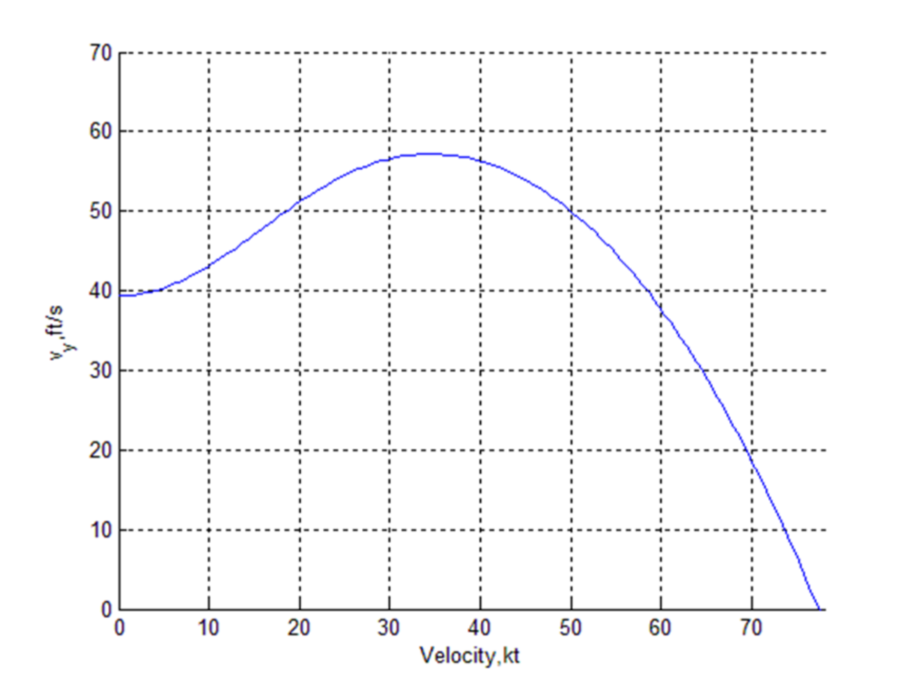


Performance



AURORA Power Required vs. Forward Flight Velocity

According to the mission profile, forward flight happens mainly after unloading relief supplies and returning to the recycling base. At this period the weight of the UAV is about 940lb.The Horsepower-Velocity curve can be drawn by using MATLAB program. In this figure, induced power, parasite power, profile power and total power required are shown respectively. What’s more, from the total power curve the max-endurance speed and max-range speed can be found.



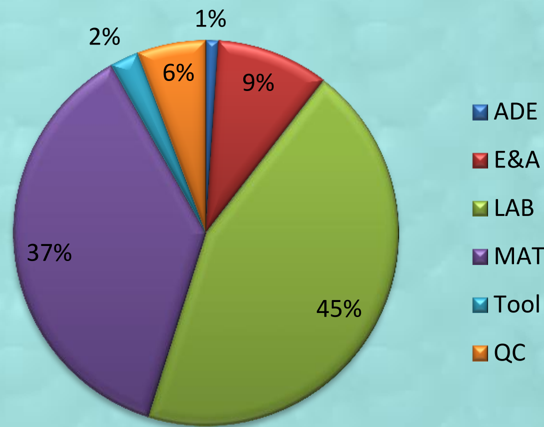
Climb Rate Curve in Forward Flight

The AURORA is a tip jet propelled coaxial UAV. It is capable to perform a climb at a maximum rate of 58 ft/s at a forward speed of 35 knot.

Life Cycle Cost Analysis

Production Cost

Categories	Cost/$FY16
C_{ade}	$ 10,129
$C_{(e+a)}$	$ 90,000
C_{lab}	$ 425,034
C_{mat}	$ 353,741
C_{tool}	$ 23,015
C_{qc}	$ 55,254
AEP	$ 957,174



Operation Cost

Operation Cost	Parts	COST
	Unit	$/FH
Direct Operation cost	Flight Cost	623
	Maintenance Cost	157
	Depreciation Cost	496
	Landing Cost	3
Indirect Operation Cost	Training Cost	536
Total Operation Cost		1,815

NUAA's AURORA is an high performance and affordable low operating cost UAV to execute the humanitarian vital supply mission is a disaster zone around the world. Overall, the operating cost of the AURORA is about $1,815/HR while capable of carrying a 550 lb payload.