Boeing Drone V2

BOEING

NAU
NORTHERN ARIZONA UNIVERSITY
College of Engineering, Informatics, and Applied Sciences

Presented by: Dylan Boeholt, Andre Bonillas, Connor Davidson, Jeremy Malmo, and Michael Zielinski

Project Description/Overview

Statement:

- We will Develop a Boeing Utililty Drone with Variable Payload Capacity (Version 2)

Description/Objective:

- Design a drone frame utilizing commercially available parts
- engage and deploy different payloads, while remaining airborne
  - The payload will also include a camera for potential surveying
- must be able to return to user and deliver/retrieve a payload to/from a desired location/target
- Sponsor:
  - Boeing Company, Mesa, AZ Facility (Defense, Space and Security Division)

Importance:

- Could satisfy a need for a more affordable and easier to manufacture, payload capable drone
  - Drone could be used to deliver and receive any kind of package,
  - could also be used for emergency reponse to deliver first aid materials or other emergency supplies
- Necessity for remote piloted drones that are durable, easy to fly, and can return to the user while performing tasks

Background & Benchmarking

Background:

- Design 1: Boeing drone Version 1 (Hi-Jax); NAU class of 2022 team
  - Only the drone was developed, light weight and compact, 6.8 lbs total weight
  - Pros: Lightweight, compact, durable, and a good jumping off point for our project
  - Cons: Not stable and no payload capabilities.

- Design 2: Aurelia X8 Pro; 8 rotor drone
  - Designed to carry a heavy payload, 10 kg
  - Pros: Heavy payload capabilities
  - Cons: Expensive and more rotors means more things to break.

- Design 3: Aurelia X6 standard; 6 rotor drone
  - Carries a lighter load, 1.5-3kg, releasable payload system
  - Pros: Less likely to break and cheaper than Design 2
  - Cons: Light payload capabilities and expensive

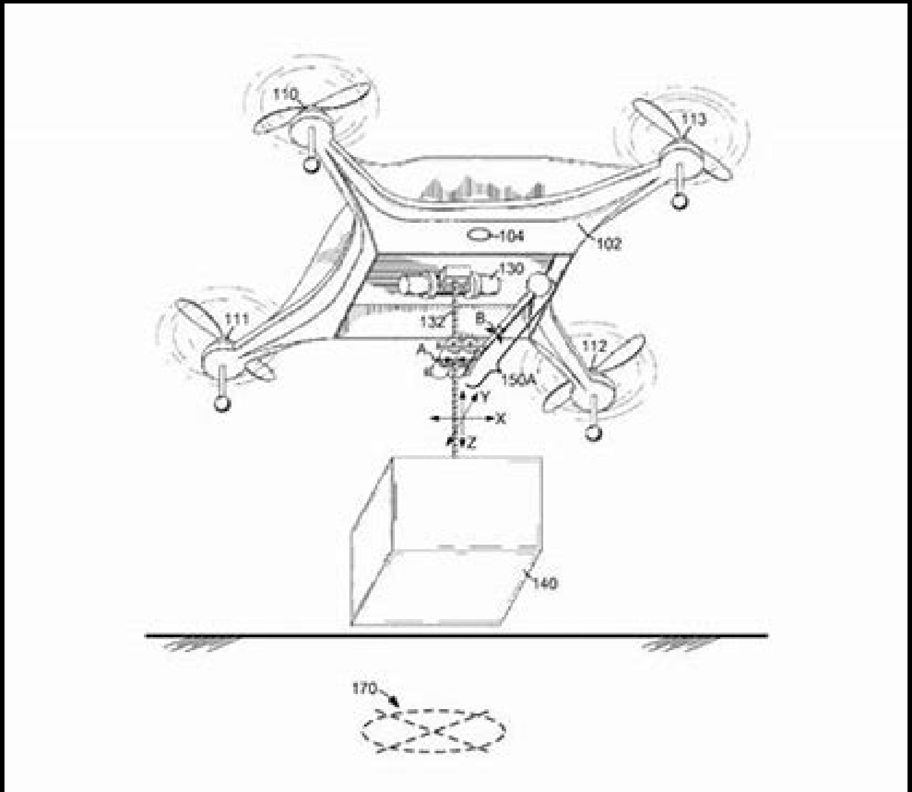
Benckmarking/Goals

- Drone must be able to pick up and drop off a payload, and interact with it (operating the camera)
- Payload will be heavy in relation to the overall weight of the craft (minimum of 30% of total weight)
- Overall compact and minimal design
- Optimize in-flight stability with incorporation of payload interchange system

- D.O.R.I.S. Dynamic – Overhead – Reconnaissance – and Interchange – System

Customer Requirements

- High mobility
- Compact Dimension
- Complete Boeing Recon Mission
- Payload Capacity
- Battery Capacity for small mission
- Cost Efficiency
- Thrust Efficiency
- F.A.A. Registered



Engineering Requirements

- Thrust to weight ratio of at least 1:3
- Under 36"x36"x36"
- Complete Course < 10 minutes
- Payload >= 5 lb
- Time of flight > 10 minutes
- Total Cost under $3000
- Lift 30% of total system weight
- Meets FAA requirements

QFD

- Thrust to weight ratio and payload capacity are of most importance

		Technical Requirements							
Customer Needs	Customer Weights: 1-5	Thrust to weight ratio	Compact Design	Complete Course	Payload	Time of flight	Total Cost under $3000	Lift % of total weight	Meets FAA requirements
High mobility	4	3	2	2	2			3	
Small	1	1	3					2	
Complete Boeing Recon Mission	5			3	2	2			2
Payload Capacity	5	2			3			3	
Battery Capacity for small mission	4			2		3	2	1	
Cost Efficiency	3		2				3		
Thrust Efficiency	4	3			2			3	
F.A.A. Registered	5								3
Technical Requirement Units			Inches	minutes	pounds	minutes	USD	% pounds	
Technical Requirement Targets		1:03	Under 3(	< 10	> 5	> 10	>3000	30	

QFD

System QFD

Project:	Boeing Drone V2
Date:	9/16/2024

3 Highes on scale

	1	2	3	4	5	6	7	8
High mobility	3							
Small		2						
Complete Boeing Recon Mission	2	3						
Payload Capacity		2						
Battery Capacity for small mission	3	1	3					
Cost Efficiency	2	2		2	2		3	
Thrust Efficiency	3			3	2	2		

Customer Needs	Customer Weights: 1-5	Thrust to weight ratio	Compact Design	Complete Course	Payload	Time of flight	Total Cost under $3000	Lift % of total weight	Meets FAA requirements
		Technical Requirements							
High mobility	4	3	2	2	2			3	
Small	1	1	3					1	
Complete Boeing Recon Mission	5			3	2	2			2
Payload Capacity	5	2			3			3	
Battery Capacity for small mission	4			2		3	2	1	
Cost Efficiency	3		2				3		
Thrust Efficiency	4	3			2			3	
F.A.A. Registered	5								3
Technical Requirement Units			Inches	minutes	pounds	minutes	USD	% pounds	
Technical Requirement Targets		1:03	Under 36	< 10	> 5	> 10	>3000	30	
Absolute Technical Importance		9	7	7	9	5	5	11	5
Relative Technical Importance									

Literature Review (Dylan)

- Engineering Statics: Chapter 4 Moments and Static Equivalence
- Engineering Statics: Chapter 7 Centroids and Centers of Gravity
- Design and Analysis of a Topology-Optimized Quadcopter Drone Frame
- Embry-Riddle Aeronautical University Scholarly Paper. This source provides equations to calculate the thrust of propellers
- Quadcopter Body Frame Model and Analysis
- Code of Federal Regulations Title 14 Chapter 1 Subchapter F Part 107
- How to Calculate & Measure Propeller Thrust

Literature Review (Andre)

- Book & chapters:
  - Make: Getting Started with Drones – chapter 12 - book
    - Describes how to implement a camera into a drone design and how to control it
  - Building Your Own Drones: A Beginner's Guide to Drones, UAVs, and ROVs Chapter 12 - book
    - Describes how to incoporate accessories such as payloads into a drone's overall design
- Papers:
  - "A Practical Perspective on the Drone-with-a-Slung-Load Problem." - Journal
    - Demonstrates drone flight behavior with a payload that is suspended (slung) below the aircraft
  - "Quadcopter Design for Payload Delivery." - Journal
    - provides insight into constructing a drone to carry a payload, such as flight behavior and structural design
  - "Package Retrieval system with funneling mechanism." Patent
    - Demonstrates potential payload retrieval mechanism, using 2 sloped mating surfaces
- Standard:
  - FAA small, unmanned aircraft weight requirements for registration (0.55 - 55 lbs) or (0.25 - 25 kg) - FAA.gov
    - Specifies the weight range for the FAA classification of a small unmanned aircraft (drone)
- Other online sources:
  - "Payloads for Drones in Emergency Response: Guide to what UAVs Carry." - dslrpros.com - article
    - Details different type of payloads that drones can carry (active, passive, dispensable)
  - "Heavy Lift Payload Drones." Uavsteminternational.com - website
    - Details existing drone designs that are intended to carry large payloads (>10kgs)
  - "Best Drones using a payload release mechanism – uavsystemsinternational.com - website
    - Details a drone that utilizes a drop mechanism for payload delivery

Literature Review (Connor)

- Website:
- [1]“Aircraft Inquiry" Faa.gov
  - This website is where we will register our drone at.
- [2]“5 Best Heavy Lift Drones [Updated 2020] Large Drones High Lift Capacity,”
  - This website helps us baseline our project by giving us similar drones to our project
- Journal Papers:
- [3] “The Current Opportunities and Challenges in Drone Technology,”
  - This journal outlines some current opportunities and challenges with drones today
- [4] “Emerging technologies and the use case: A multi-year study of drone adoption,”
  - This journal evaluates drone technology over a multi-year study
- [5] "IEEE Approved Draft Standard for Drone Applications Framework,"
  - This journal explains IEEE approved draft standards for drone application
- Books:
- [6] *2024 - 2025 FAA Drone License Exam Guide*. 2024.
  - This book is an exam guide for the FAA drone license.
- [7] *Remote Pilot - Small Unmanned Aircraft Systems Study Guide (Federal Aviation Administration): FAA-G-8082-22*. 2018.
  - This book is a study guide for FAA regulations for small unmanned aircraft systems

Literature Review (Jeremy)

Websites

- Devin et al., “How to choose FPV drone motors - considerations and Best Motor Recommendations,” How to Choose FPV Drone Motors – Considerations and Best Motor Recommendations, https://oscarliang.com/motors/ (accessed Sep. 16, 2024).
- J. and Daniel, “The UAV Chronicles,” Step 5: Motor Selection, https://uav.jreyn.net/ (accessed Sep. 17, 2024).

Journals

- K. TAKATO and S. SHIRAYAMA, “Development of a 3D-printed device evaluating the aerodynamic performance of rotary wings,” Journal of Advanced Mechanical Design, Systems, and Manufacturing, vol. 12, no. 1, pp. JAMDSM0027–JAMDSM0027, 2018, doi: 10.1299/jamdsm.2018jamdsm0027.
- D. BBVL, D. Pal Singh, S. Kumar Kuppa, and M. Jayanthi Rao, “Design optimization of drone BLDC motor for delivery service applications,” Materials today : proceedings, 2023, doi: 10.1016/j.matpr.2023.07.370.

Books

- W. H. Yeadon and A. W. Yeadon, Handbook of Small Electric Motors. New York: McGraw-Hill, 2001.
- N. Barrera, S. Martin, and M. Stewart, Unmanned Aerial Vehicles. New York: Nova Science Publishers, Inc, 2021.

Standard

- “The Ultimate Guide to Heavy Lift Drone Motors,” JOUAV, https://www.jouav.com/blog/heavy-lift-dronemotors.html#:~:text=Ideally%2C%20for%20standard%20drones%2C%20a,for%20smooth%20and%20controlled%20flight. (accessed Sep. 17, 2024).

Literature Review (Michael)

- Books:
  - Building Your Own Drones: A Beginner's Guide to Drones, UAVs, and ROVs (Chapter 14: Software) [22]
  - Make: Getting Started with Drones (Chapter 4: Flight Controllers) [21]
- Papers:
  - A Review on the State of the Art in Copter Drones and Flight Control Systems 2024 [19]
  - Development of Drone based Delivery System using Pixhawk Flight Controller [18]
  - Payload Manipulation for Seed Sowing Unmanned Aerial Vehicle through interface with Pixhawk Flight Controller [17]
- Standard:
  - ASTM F3005-22 Standard Specification for Batteries for Use in Small Unmanned Aircraft Systems (sUAS) [20]
- Websites:
  - OscarLiang.com - useful general information about electronic part selection/drone building [14]
  - UAV.ireyn.net - another college capstone that built a quadcopter [15]
  - Ardupilot.org - Ardupilot flight controller and guide for DIY building of drones [16]

Mathematical Modelling (Dylan)

Payload Weight: $W = 18lb$

$W \ x \ 0.3 = P$ $18 \ lb \ x \ 0.3 = 6 \ lb$

Thrust to Weight Ratio

Thrust > Weight and Payload to create lift

$W + P = 18 \ lb + 6 \ lb = 24 \ lb$

Thrust > 24lbf for lift

Goal Thrust to Weight Ratio = 1.6

$T = (W + P)x \ 1.6 = 38.4 \ lbf$

Thrust of the propeller can be calculated using the following equations:

$$F_{thrust} = \dot{m} \cdot [V_e - V_0]$$

Where:

$\dot{m} = mass \ flow \ rate$

$V_e = exit \ velocity \ of \ air$

$V_0 = entrance \ velocity \ of \ air$

$$\dot{m} = \rho \cdot V_p \cdot A = \rho \cdot V_p \cdot \pi r^2$$

Mathematical Modelling (Andre)

- Maximum weight calculations based off FAA regulations:
  - Max weight of system <= 25 kg
  - W_D = Drone weight
  - W_P = payload weight = 0.3W_D
  - W_D + 0.3W_D = 25 kg
  - W_D MAX = 19.2 kg
  - W_P MAX = 0.3W_D = 5.8 kg
- Desired weight calculations based off customer & engineering requirements:
- W_P = 5 kg
- W_D = W_P/0.3 = 16.7 kg
- Desired weight of system = 21.7 kg
- Force of payload on connection apparatus:
- F = mg: F = (5kg) * 9.81 m/s^2 = 49.1 N

Mathematical Modelling (Connor)

- Course Length and Speed Calculations

  120 + Sqrt(240^2 +90^2) + 90 + Sqrt(240^2 +90^2) + 120 = 842.64 feet

  To complete the course in 10 minutes

  842.64 feet x 1/10min x 1 min/60 s = 1.4044 ft/s

- Payload Stress Equations

  $F = m*g$

  $\sigma = Fn/ A$

  $\tau = Fp/ A$

  $\varepsilon = dl / lo$

  $E = \sigma / \varepsilon$

Mathematical Modelling (Jeremy)

Motor Selection: Thrust Ratio goal of 3:1 Projected total system weight: 21lb
(min. Of 6.3lb payload) =9.52 kg

TWR = F/W

$TWR = \frac{3}{1} = \frac{(9.52kg)*3}{9.52kg} =$ Total thrust 28.56 N

QUAD-COPTER (4)

$\frac{Thrust}{\#\ of\ motors} = \frac{28.56}{4} =$ 7.14 kg required per

HEX-COPTER (6)

$\frac{Thrust}{\#\ of\ motors} = \frac{28.56}{6} = 4.76\ kg$ required per

Propeller Thrust: $0.5 * \rho * \pi r^2 * [V_e^2 - V_o^2]$

$\rho = air\ density$ r = propeller radius

V_e = Air Exit Velocity V_o = Air entrance Velocity

Mathematical Modelling (Michael)

- Battery capacity formulas
  - Power formula (W): P = V x I
  - Energy consumption over time (Wh): E = V x I x T
  - Capacity from voltage (Ah): C = E/V
- Assumptions: 700W per motor, 15 minute flight time, 4 motors at max draw, 22.2V battery
  - 700W * 0.25hr = 175Wh
  - 175Wh * 4 motors = 700Wh
  - 700Wh / 22.2V = 31.53Ah (31,530mAh) battery required for ONLY MOTORS with NO step down

Schedule & Gantt Chart

Boeing Drone V2 Gantt Chart (Semester 1)
(TEAM ASSIGNMENTS)
(INDIVIDUAL ASSIGNMENTS)
(NEEDS EDITING)

Tasks	DUE DA1	Number of Hours Estima	Actual Number of Ho	Tasks Assigned To
HW00 - Academic Integrity Assignment	29-Aug	2	2	Team
HW01 - Project Signup	30-Aug	0.5	0.5	Team
Timecard Wk1	3-Sep	0.5	0.5	Team
Staff Meeting #1 (Wk2)	4-Sep	2.5	2.5	Team
Team Charter	6-Sep	2	3	Team
HW02 - Solidworks Review	8-Sep	5	5	Team
Timecard Wk2	9-Sep	0.25	0.25	Team
Staff Meeting #2 (Wk3)	11-Sep	2.5	2.5	Team
Timecard Wk3	16-Sep	0.25	0.25	Team
Presentation 1	18-Sep	8		Team
P1 (Overview and Background)	18-Sep	0.5		Jeremy, Dylan, and Andre
P1 (Lit Review)	18-Sep	2		Team
P1 (Mathmatical Modeling)	18-Sep	1		Team
P1 (Schedule/Gantt Chart)	18-Sep	2		Connor
P1 (Budget)	18-Sep	2		Micheal
P1 (Summary)	18-Sep	0.5		Andre
Presentation 1 - feedback to other teams	18-Sep	0.5		Team
Peer Eval 1	19-Sep	0.5		Team
Timecard Wk4	23-Sep	0.25		Team
Staff Meeting #3 (Wk5)	25-Sep	2.5		Team
Timecard Wk5	30-Sep	0.25		Team
Staff Meeting #4 (Wk6)	2-Oct	2.5		Team
HW03	4-Oct	5		Team
Timecard Wk6	7-Oct	0.25		Team
Presentation 2	9-Oct			Team
[Insert Sub Tasks for Presentation 2 here]				
Presentation 2 - feedback to other teams	9-Oct			
Peer Eval 2	10-Oct			
Timecard Wk7	14-Oct			
Staff Meeting #5 (Wk8)	16-Oct			
Report #1	18-Oct			
Timecard Wk8	21-Oct			
Staff Meeting #6 (Wk9)	23-Oct			
Website Check #1	25-Oct			
Timecard Wk 9	28-Oct			
Staff Meeting #7 (Wk10)	30-Oct			
Analysis Memo	1-Nov			
Timecard Wk10	4-Nov			
Presentation 3	6-Nov			
[Insert Sub Tasks for Presentation 3 here]				
Presentation 3 - feedback to other teams	6-Nov			
Peer Eval 3	7-Nov			
Timecard Wk11	12-Nov			
1st Prototype Demo	13-Nov			
DAC meeting extra credit	15-Nov			
Timecard Wk 12	18-Nov			
Staff Meeting #9 (Wk13)	20-Nov			
HW04 - Individual Analysis	22-Nov			
Timecard Wk13	25-Nov			
Report #2	27-Nov			
Staff Meeting #10 (Wk14)	27-Nov			
Timecard Wk14	2-Dec			
Final CAD and Final BOM	3-Dec			
[Insert Sub Tasks for Final CAD and Final BOM here]				
2nd Prototype Demo	4-Dec			
[Insert Sub Tasks for 2nd Prototype Demo here]				
2nd Proto Demo - feedback to other teams	4-Dec			
E-fest Extra Credit	6-Dec			
Project Management for 486C	6-Dec			
Website Check #2	7-Dec			
(FINAL) Peer Eval 4	8-Dec			
Course Eval Extra Credit/Close	8-Dec			
Timecard Wk15	9-Dec			

Week 1 (Aug 26 - Se	Week 2 (Sept 2 - Sept	Week 3 (Sept 9 - Sept 1	Week 4 (Sept 16 - Sept 2	Week 5 (Sept 23 - Sep	Week 6 (Sept 30 - Oct	Week 7 (Oct 7 - Oct 1	Week 8 (Oct 14 - Oct 2	Week 9 (Oct 21 - Oct 2	Week 10 (Oct 28 - Nov	Week 11 (Nov 4 - Nov 1	Week 12 (Nov 11 - Nov 17	Week 13 (Nov 18 - Nov2	Week 14 (Nov 25 - Dec 1)	Week 15 (Dec 2 - Dec 8)

Budget

Team:	Boeing V2		Budget:	$ 3,300.00			
Team Number:	F24toSp25_13		Expense:	$ 3,300.00			
Speedchart:			Remaining:	$ -			

Date	Vendor	Item	Quantity	Cost per Unit	Cost	Status	Notes
9/10/24	Amazon	PLA Filament	1	$ 15.26	$ 15.26	Delivered	Jeremy Paid
9/17/24	Staples	64GB EliteX CL10 microSD (2 pack)	1	$ 16.46	$ 16.46	In-Store	Jeremy Paid
		Pixhawk 6C Flight controller	1	$ -	$ -		Salvaged
		Holybro PM07	1	$ -	$ -		Salvaged
		Holybro M8N GPS/Compass	1	$ -	$ -		Salvaged
		Xing 2814 880KV Motor	4	$ -	$ -		Salvaged
		EFlite EFLA1040A EFC	4	$ -	$ -		Salvaged
		FlySky IA6B 6-channel Receiver	1	$ -	$ -		Salvaged
		RC Controller	1	$ -	$ -		Salvaged
		6000mAh battery	1	$ -	$ -		Salvaged
		Other electronic components (for drone flight only, not payload)	1	$ -	$ -		Salvaged
		Donated 3D filament (ABS & PLA)	1	$ -	$ -		Donated
		Propellers	4	$ -	$ -		Salvaged
		GoPro Hero (the little one)	1	$ 217.26	$ 217.26		GoPro.com
		New battery	1	$ 519.69	$ 519.69		Based on Tattu G.Tech 22Ah
		New motors	6	$ 60.00	$ 360.00		2 extras, high end
		New ESCs	6	$ 25.00	$ 150.00		Based on research experience
		New props	6	$ 45.00	$ 270.00		Based on SwellPro Fisherman Max 16" carbon fiber props (high end)
		Various hardware pieces	1	$ 100.00	$ 100.00		Based on hardware prices
		Frame Materials	1	$ 1,000.00	$ 1,000.00		Estimate based on 3D printing from Hi Jacks
		Travel to/from PHX	2	$ 150.00	$ 300.00		Based on Nissan Versa gas mileage, free housing, food on your own
		Payload attachment system	1	$ 200.00	$ 200.00		Servos/design materials
		Discretionary Budget	1	$ 151.33	$ 151.33		Leftover

Summary and Future Plans

- We are tasked with building and iterating on a FAA certified drone for the Boeing Company that can pick up and drop off a payload that is 30% of the total weight of the drone autonomously.
- The drone must also be able to complete the Boeing test course while carrying the payload and when complete, be able to take a picture of the team.
- In the next few weeks, we plan on solidifying a design for the drone, do material testing, and start testing the drone itself.
- D.O.R.I.S. coming soon

Questions?

References

- Dylan Boeholt:
- Books:

- [1]D. W. Baker and W. Haynes, Statics: Moments and Static Equivalence. Available: https://engineeringstatics.org/Chapter_04.html
- [2]D. W. Baker and W. Haynes, Statics: Moments and Static Equivalence. Available: https://engineeringstatics.org/Chapter_07.html
- Papers:
- [3] Design and Analysis of a Topology-Optimized Quadcopter Drone Frame. Available: https://www.researchgate.net/publication/379362481_Design_and_Analysis_of_a_Topology-Optimized_Quadcopter_Drone_Frame
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- Standard:
- [6]"14 CFR Part 107 -- Small Unmanned Aircraft Systems," www.ecfr.gov. https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107
- [7]A. Staff, "How to Calculate & Measure Propeller Thrust," Tyto Robotics, Mar. 02, 2023. https://www.tytorobotics.com/blogs/articles/how-to-calculate-propeller-thrust?srsltid=AfmBOooqC8rrGYyaPLPQVlG-U45EKQp_7YPFy7cnkC4brYY3msxqeBEV (accessed Sep. 18, 2024).
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- Michael Zielinski:
- [14] O. Liang, “FPV drone tutorials and reviews,” Oscar Liang, https://oscarliang.com/ (accessed Sep. 18, 2024).
- [15] “Step 7: Electronics selection,” Atom, https://uav.jreyn.net/quadcopter-design/step-7-electronics-selection (accessed Sep. 18, 2024).
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