Kestrel Aeronautics: KA-Ranger

Madison Smith[1], Jason Burke[1], Lindsey Dow[1], Wyatt Dritz[1], Thomas Key[1], Nate Matthews[1],
John McDonough[1], Connor Hawkins[2]
University of Alabama in Huntsville, Huntsville, AL, 35805

As combat environments continue to evolve, there is a growing need for dedicated aircraft to provide close air support to ground forces. In response to the 2021 AIAA Undergraduate Team Aircraft Design Competition RFP, Kestrel Aeronautics developed the KA-Ranger, an affordable, light attack aircraft to operate from austere fields and replace current helicopters in close air support missions. The design must accomplish an attack mission with full weapons payload, cruise for 200 nmi at an altitude ≥10,000 ft, and loiter 4 hours. It must also complete a long-range ferry mission of at least 900 nmi range at 60% payload, cruising at an altitude ≥18,000 ft. Both missions require reserves for an additional 3,000 ft climb and 45 minute loiter. A survey of current attack aircraft yielded the initial design including a turboprop engine, low mounted rectangular wings, conventional tail, and retractable tricycle landing gear. The aircraft weighs approximately 12,000 lbf with two crew members, an integrated gun, and 3,000 lbf of externally mounted armament. Current design activities include material selection, detailed structural design, weapon and fuel placement with stability analysis, drag assessment, and power analysis to confirm the KA Ranger's flight performance.

I.   Nomenclature

C_{DO}	Drag Coefficient at Zero Lift
C_D	Drag Coefficient
C_L	Lift Coefficient
AIAA	American Institute of Aeronautics and Astronautics
AFLAA	Austere Field Light Attack Aircraft
BSFC	Brake-specific Fuel Consumption
CAS	Close Air Support
ESHP	Equivalent Shaft Horsepower
KA	Kestrel Aeronautics
MTOW	Maximum Takeoff Weight
NACA	National Advisory Committee for Aeronautics
RFP	Request for Proposals
ROC	Rate of Climb
SHP	Shaft Horsepower
TRL	Technology Readiness Level

II.   Introduction

Kestrel Aeronautics aims to design an austere field light attack aircraft (AFLAA) for the AIAA competition that is a more efficient and cost-effective alternative to previous and current close air support (CAS) aircraft and replace helicopters in comparable missions. The main requirements of this aircraft include austere field performance, survivability, adaptable weaponry, an integrated gun, 15,000 flight hours over 25 years, 2 crew members, and a service ceiling of 30,000 ft. The aircraft is required to complete a design mission focused on delivering air support with a 3000 lbf weapons payload and a long-range ferry mission at 60 percent of payload requirement. Following the review of these design considerations, the design team researched similar aircraft that would be able to match the required performance and specifications. A down selection of traits from these similar aircraft was performed to produce a baseline design. Currently, the team at Kestrel Aeronautics has selected materials and performed detailed analyses on the structural design, stability in terms of weapon and fuel tank placement, drag, and engine power to refine the baseline and produce the current conceptual design of the KA-Ranger as presented in this document.

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[1]Aerospace Engineering Senior, Department of Mechanical and Aerospace Engineering, AIAA Student Member
[2]Mechanical Engineering Senior, Department of Mechanical and Aerospace Engineering, AIAA Student Member

III. RFP Overview

A. Requirements, Objectives and Goals

The conceptual design of the KA-Ranger aircraft was guided by the AFLAA request for proposal (RFP). The mandatory requirements are as follows: [1]

- [R] Austere Field Performance: Takeoff and landing over a 50 ft obstacle in ≤ 4,000 ft when operating from austere fields at density altitude ≤ 6,000 ft with semi-prepared runways at a California Bearing Ratio of 5
- [O] Survivability: Consideration for survivability, such as armor for the cockpit and engine, reduced infrared and visual signatures, and countermeasures (chaff, flares, etc.).
- [R] Payload: 3,000 lbf of armament
- [O] Provisions for deploying a variety of weapons, including missiles, rockets, and 500 lbf (max) bombs
- [R] Integrated gun for ground targets
- [R] Service life: 15,000 hours over 25 years
- [R] Service ceiling: ≥ 30,000 ft
- [R] Crew: Two, both with zero-zero ejection seats

The RFP also specified the additional goals of providing a "best value" design that meets performance specifications, considers both acquisition and operational cost over a 25 year service life, offers better survivability than current helicopters on the missions. The aircraft must be certifiable by the military standard airworthiness (MIL-STD-516C), consistent with Joint Service Specification Guides, and flexible in design without adding undue cost. Assumptions on the critical technologies were advised to be made at TRL 8 or above [1].

B. ConOps

The AFLAA RFP defines two missions that the KA-Ranger must complete. These are a design mission, focusing on the KA-Ranger's ability to deliver air support, and a ferry mission, to test the KA-Ranger's range performance. The design mission is shown in Fig. 1a. The KA-Ranger must warm up and taxi within 5 minutes, take off from an austere field, climb to ≥ 10,000 ft, and cruise for 100 nautical miles before descending to 3,000 ft and loitering for four hours without dropping any munitions. After target engagement and weapons deployment, the KA-Ranger is expected to climb back to its cruise altitude, cruise for another 100 nautical miles before landing. In order to meet the requirements of the design mission the aircraft should have a top speed of at least 300 kts in order to cover the 100 nmi distance within 20 minutes. The ferry mission, shown in Fig. 1b, requires identical takeoff procedures, climb to its best range and speed altitude ≥ 18,000 ft, cruise for 900 nautical miles, and descend to land at an austere field while carrying 60% of the design payload. In both missions, the KA-Ranger must have reserves sufficient to climb to 3,000 feet and loiter for an additional 45 minutes. [1].
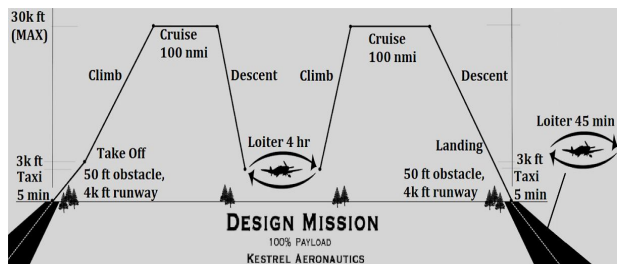
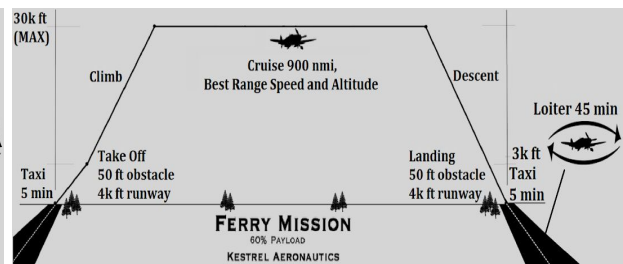

Fig. 1a Design Mission KA-Ranger ConOps   Fig. 1b Ferry Mission KA-Ranger ConOps

The team specified a design goal of producing a low cost aircraft. This would be achieved by low cost per unit, flight hour, and maintenance hour, and having an adaptable weapons system capable of carrying and launching multiple classes of weapons. Range and endurance exceeding the range and loiter time requirements are also goals. Kestrel Aeronautics includes a project lead and chief engineer. The other members are arranged into three groups. The first group consists of Aerodynamics, Structures, and CAD. The second group includes Stability, Avionics, and Mechanical Systems. Finally, the third group is Performance and Propulsion. This arrangement was chosen to address the many aspects of aircraft design and also facilitate cooperation between similar topics within groups. The three groups meet weekly to discuss design status and changes.

As shown in Fig. 2, a House of Quality was produced to organize the design requirements and constraints. The requirements specifically stated in the RFP are starred while the unstarred are objectives or implicit design constraints derived from the RFP. The team focused on design features including high thrust to weight ratio, low structural weight to takeoff weight, low stall speed, anti-aircraft measures, low maintenance hours, modular weapon carrying system, large cockpit for crew of two, low part count, compatibility with existing systems, and an integrated gun. The black dot, blank circle, and blank triangle indicate high, moderate, and weak correlations, respectively. The direction of improvement triangles indicate which direction the parameter would optimize. On the right side, the requirements are ranked according to importance to the customer in the RFP with exceptions such as the objectives of safety and survivability being above other requirements. The implicit requirements of long range and endurance are ahead of the required service ceiling and number of crew members. These alterations to the rank were made considering the purpose of the aircraft for close air support with long range and endurance missions carrying weapons for attack. Additionally, the aircraft will likely be in a hostile environment, need to operate on an austere field, and be easily serviceable at a temporary base.

Direction of Improvement	High Ts/Wto ▲	Low Wstruct/Wto ▼	Low Stall Speed ▼	Anti-Aircraft Fire Countermeasures ◇	Low Maintenance Man Hours to Flight Hours ▼	Low SFC ▼	Modular Design of Weapon Carrying System ◇	Large Cockpit (2 Seats) ◇	Low Part Count ▼	Compatibility with Existing Systems ◇	Integrated Gun ◇	Weight	Rank
Short Takeoff and Landing on Austere Fields*	●	○	●	▽			▽	○				0.14	1
Safety and Survivability	○		○	●	○		○	▽			●	0.14	2
Payload Capability*	○	●	▽			○	○	○			▽	0.11	3
Integrated Gun*		○		●			▽			▽	●	0.1	4
Long Service Life*	▽			○	●				●	○		0.09	5
Long Endurance	▽	▽		▽		●		▽				0.09	6
Long Range	▽	▽		▽		●		▽				0.08	7
Adaptable Weapons System		○					●			○		0.08	8
High Service Ceiling*	▽	▽							▽			0.07	9
Two Crew Members*					▽			●	▽	▽		0.05	10
Low Cost	▽	○		○	●		●	○	○	○	▽	0.05	11

Fig. 2 House of Quality

IV. Discussion of Similar Mission Aircraft

Table 1. Notable Parameters of Similar Aircraft [2-6]

Aircraft	Aircraft Type	Max Speed (kts)	Service Ceiling (ft)	Range (nmi)	MTOW (lbf)
AD/A-1 Skyraider	Piston-Engine	280	28,500	1143	18,398
A-29	Turboprop	321.5	35,000	721	11,905
A-67 Dragon	Turboprop	371	35,000	1633	10,200
KA-Ranger	Turboprop	307	29,323	1300	12,000
T-50	Turbofan	992	48,000	999	27,117
SU-25	Turbojet	526.5	23,000	538	42,549
AH-64 Apache	Rotorcraft	158	20,000	257	17,650

Prior to developing the conceptual design of the KA-Ranger, the team researched many similar mission aircraft spanning the categories of piston-engine, turboprop, turbofan, turbojet, and rotorcraft. Table 1 shows the comparison

of similar mission aircraft including each type of aircraft and performance capabilities. The AD/A-1 Skyraider does not meet the maximum speed requirement. The A-29 does not meet the range requirement. The A-67 meets the maximum speed, service ceiling, and range requirements, but the MTOW is too low to support the weapons and fuel needed to complete the required missions. The T-50 and SU-25 do not meet the range requirement. The AH-64 does not meet the maximum speed, service ceiling, or range requirements which is consistent for all identified rotorcraft. Though turbofan aircraft with the ability to accomplish the given requirements were identified, their lack of performance at low altitudes led the team away from designing a turbofan aircraft. As the KA-Ranger baseline design incorporates a turboprop engine and should replace current military helicopters, some of the similar turboprop and rotorcraft aircraft are discussed here.

Contemporary military propeller-driven aircraft utilize turboprop engines to achieve the performance that piston-engines tend to lack. Turboprops, such as the Super Tucano (A-29), accommodate multiple hardpoints for various deployable weapons. Of the identified militarized turboprops, all utilize straight, low to mid-mounted wings with taper and dihedral. Rotorcraft are another common modern approach to close air support. However, the considered rotorcraft have an average service ceiling of 15,000 ft, maximum speed of 170.7 kts, and range of 308.8 miles. To meet the requirements of the design mission, the KA-Ranger will need to reach a 30,000 ft service ceiling and at least a maximum speed of 300 kts. Both parameters are beyond the capabilities of any identified rotorcraft. Fig. 3 shows the comparison of each aircraft in terms of MTOW and maximum speed. Table 1 and Fig.3 were particularly useful for the design team in visualizing the differences in performance of each aircraft type and individual aircraft. For instance, rotorcraft tended to have the lowest range, service ceiling, and maximum speed while the turbofans and turbojets were the opposite.
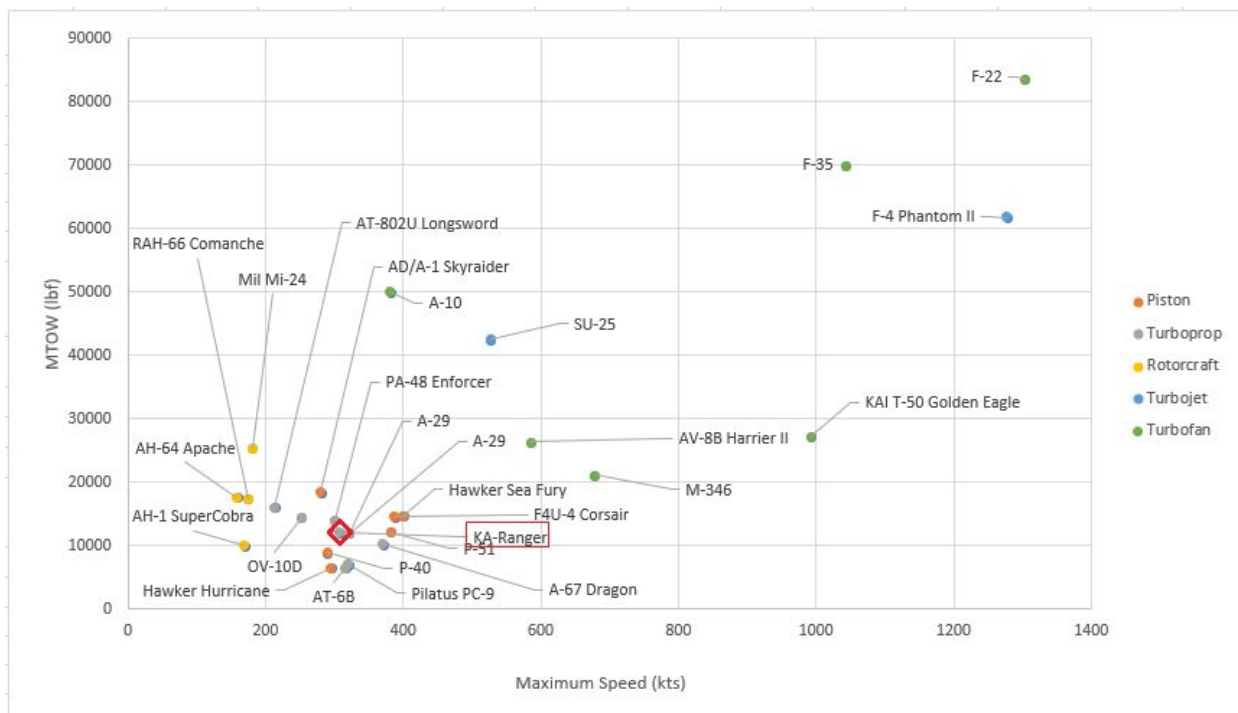

Fig. 3 MTOW vs Maximum Speed

V.   Baseline Concept Description

In this conceptual stage of the development, Kestrel Aeronautics focused on determining an engine type, approximate MTOW, wing shape and loading, empennage style, landing gear configuration, weapons placement, and fuselage sizing to produce a baseline aircraft. These choices were based off of the similar aircraft data and further research on alternative designs. Then, the team down-selected to the preferred concept, resulting in the baseline KA-Ranger shown in Fig. 4.
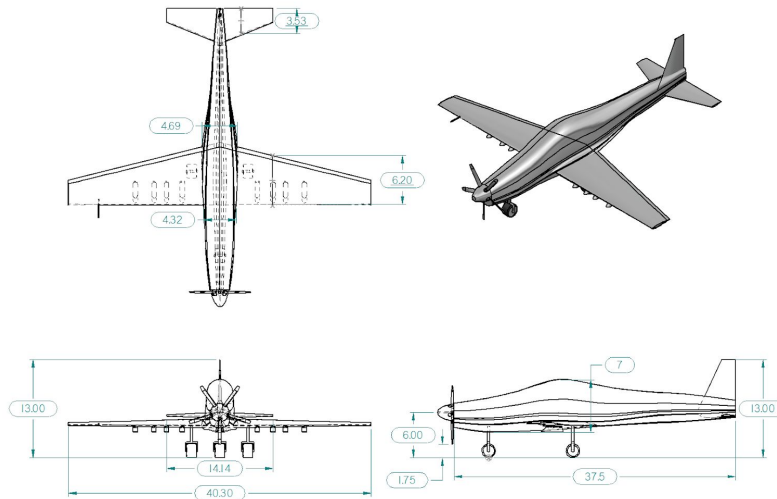
Fig. 4 Baseline KA-Ranger Conceptual Design

Piston, turboprop, turbofan, and turbojet engines were compared before finally deciding on the turboprop. Turbojet engines are unsuitable for austere field conditions and piston engines cannot achieve sufficient performance at altitudes greater than 10,000 ft without the added complexity and fuel consumption of supercharging. The choice was between turboprop and turbofan engines. Although turbofan engines often perform better than the turboprop engines at higher altitudes, the added speed, service ceiling, range, and endurance comes at a cost in efficiency, especially at the low altitudes and airspeeds that are typical of a close ground support aircraft. The turboprop engine is capable of reaching the required speed and service ceiling, is lighter, has less moving parts, costs less per unit, has reduced maintenance costs, and lasts longer between overhauls, making it the most logical choice [7].

Weight and sizing estimates were based on the similar mission turboprop aircraft in Table 1. Similar turboprop aircraft have tapered, rectangular wings optimized for slower flight and greater weapon capacity, these traits were chosen for more effective support of ground troops. The taper ratio was set to 0.4, which produces a higher Oswald efficiency factor and emulates the low induced drag of an elliptical wing without added manufacturing complexity and greater risk of wing tip stall from more extreme taper ratios [8]. The wing was placed low on the fuselage to provide increased stability. However, this aircraft is only meant for close air support and doesn't need the superior maneuverability of a mid-wing design [9]. The average MTOW of the similar aircraft was determined to be 11,443 lbf, so the design team decided on a MTOW of 12,000 lbf for a baseline goal. Trends in the similar aircraft were examined to determine the KA-Ranger's baseline wing area of 250 ft^2 and aspect ratio of 6.5. Using these values and the rectangular wing shape, the span and chord were calculated to be 40.3 and 6.2 ft, respectively. Similar to the baseline wing design, a traditional empennage configuration is utilized. The tail must be able to provide enough lift to offset the pitching moment induced by the wing and control the pitch of the aircraft despite aerodynamic interference from the engine. The horizontal stabilizer was based off of the wing with an area of 50 ft^2, approximately 20% of the wing area, and an aspect ratio of 4 [10].

The landing gear was determined to be a retractable tricycle configuration as opposed to a taildragger due to the increased visibility while taxiing, more stability on take off and landing in crosswinds, and greater avoidance of debris on austere fields [11]. As opposed to fixed gear, retractable gear provide a 50% reduction in drag with an associated 15-20% increase in climb rate and only a small decrease in safety due to the hydraulic system failures accounting for 1% of landing gear failures [12,13].

Review of similar aircraft yielded an approximate armament weight limit of 5,005 lbf for a MTOW of 12,000 lbf with four hard points on each wing to carry an array of missiles, rockets, and bombs. External armament was chosen due to the simplicity and increased modularity. The gun is integrated into the wing to avoid timing issues with the propeller and packing issues in the nose of the aircraft where the engine and retractable landing gear are located. With external weaponry, the fuselage was designed around the engine and the pilot with tapering for aerodynamics and scaling from similar aircraft for the external dimensions. The PT6A-68 engine has a height and width of 22 and 19.5 inches, respectively, so the nose diameter was chosen to be 31 inches [14]. Meanwhile, the shoulder-width dimensions for the pilot were determined to be between 20-46 inches while the height to overhead was determined to be about 35-42 inches, resulting in the decision of a cockpit with a width and height of 46 inches and 38 inches, respectively [15].

VI.   Preliminary Design Progress

The preliminary design process evolves the baseline KA-Ranger concept, but with more details and the beginning stages of optimization. The process began with building structural, stability, aerodynamic, and performance models to assess the progress of the baseline aircraft. From there, the team decided on preliminary materials, structural design, fuel and weapons placement, an airfoil, potential high lift devices, and detailed wing shapes while also determining the service ceiling, range, and endurance of the KA-Ranger.

A. Material Selection and Structural Design

The KA-Ranger will be constructed from aluminum due to its high strength to weight ratio. Composite materials offer superior strength to weight ratios, but their maintainability and cost are major considerations. Field maintenance and repairs to a composite airframe may be more difficult than for an aluminum aircraft since aluminum has been used in military applications for decades. There are various alloys of aluminum with different properties. Aluminum-2024 is widely used because of its high strength to weight ratio and resistance to fatigue. This will be a good structural material for the KA Ranger as it will need to resist fatigue and be strong and light enough to fly for many years. Aluminum-2024 comes in different tempers, the best of which for our purposes is Aluminum-2024-T4 with a fatigue stress of 138 MPa for $5e^8$ cycles [16]. Aluminum-6061 is not as strong as Aluminum-2024 but it is easier to machine and weld as well as being resistant to corrosion, making it a suitable material to make the skin of the aircraft. Aluminum-7075 offers superior strength to Aluminum-2024 and may be used to strengthen high stress areas of the aircraft such as where the wing and fuselage join.
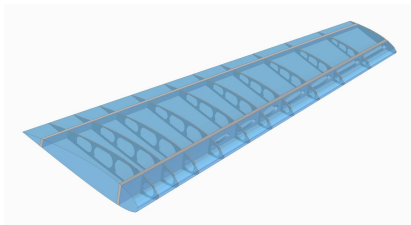

Fig. 5 Wing Structure

A two-spar design, as shown in Figure 5, was chosen to provide adequate strength in the wings. The spars are I-beams consisting of a web of Aluminum-2024 shaped to fit inside the wing with T shaped caps flash welded on to the top and bottom. The main spar is placed slightly ahead of the quarter chord to bear the majority of the load and a second spar near the trailing edge serves as an anchor point for control surfaces and high lift devices as well as providing additional support to the wing. The two spars run from the fuselage to the wingtips while a carry thru spar runs through the fuselage connecting the main spars of each wing. To reduce weight, some material will be cut away from the web of the I-beam near the wingtips where the stresses are lower than closer to the fuselage. Ribs are positioned along the span of the wing to provide its shape. The ribs are made from plates of Aluminum-2024 with material cut away in the center to reduce weight. Hat stringers of Aluminum-2024 running spanwise across the ribs, will provide support to the skin of the aircraft. A small spar with ribs supporting the leading edge will add additional strength to the wings and will protect the fuel tanks and other components mounted in the wings from potential damage in the event of a debris strike. Sheets of Aluminum-6061 will be roll formed to the shape of the wing and laid over and flash welded to the stringers to make up the skin of the aircraft. The horizontal and vertical stabilizers will each have an Aluminum-2024 spar at the leading edge and another at the trailing edge to anchor the control surfaces to. The rest of the construction of the tail will be similar to that of the wings.

The KA-Ranger will feature a semi-monocoque fuselage design [17]. Bulkheads will be constructed from plates of Aluminum-2024 cut to the shape of the desired cross sections of the fuselage. Holes will be cut in the center of the bulkheads to lighten the airframe with larger holes cut in bulkheads under less stress when under a simulated load. Aluminum-2024 I-beams running the length of the aircraft will keep the fuselage stiff while stringers hold the skin firmly to the shape of the fuselage. The skin of the fuselage will be made from Aluminum-6061 to protect the aircraft from corrosion.

In the design process for the wings and fuselage, the aircraft will first be modeled with solid spars, ribs, and bulkheads thick enough that the maximum stresses under maximum loading will be less than the fatigue stress of the materials. Once the structure is strong enough to withstand the cyclic loadings, excess material will be removed where stresses are low to reduce weight. If this design does not meet the performance requirements using a stronger

alloy such as Aluminum-7075 may be investigated or selective use of composite materials may be considered if necessary to further reduce weight.

B. Weapon and Fuel Systems Placement

The amount of hardpoints was reassessed and increased from six to eight due to a need for external storage of ammunition and potential increases in aircraft fuel capacity with a drop tank. The increase in hardpoints also allows for an increase in carried armament if the additional drop tank is not required. Determining the placement of the KA-Ranger weapons system required considerations of aircraft stability and drag. Optimum stability and balance of the aircraft requires heavier armament types to be placed closer to the fuselage, though the hardpoints allow for different configurations. With eight hardpoints and a wing-integrated gun, this optimal design can be seen in Table 2 where the weapons were chosen due to their reliability and versatility in combat situations. Increased aircraft drag is also an issue with a modular weapons system. In order to minimize interference drag effects, hardpoints must be positioned away from the fuselage and other hardpoints. An in-depth drag analysis and stability analysis will allow for more accurate placement of the weapons system.

Table 2: Optimal Hardpoint Placement

	Hardpoints Numbered from Anatomical Left to Right of Plane							
	1	2	3	4	5	6	7	8
Type	Drop Tank	MK-261 Rocket	AGM-65 Missile	MK-82 Bomb	MK-82 Bomb	AGM-65 Missile	MK-261 Rocket	Ammo Pod
Weight (lbf)	300	345	485	500	500	485	345	219

Determining the location of fuel storage, the type of fuel had to be selected. Based on military standards, current military fuel usage, and operating costs, Jet A-1 fuel was determined to be the best choice for the KA-Ranger [18]. Fuel storage was decided to be primarily within the wings of the aircraft allowing for use of empty space and more stability in-flight compared to the effects of external fuel storage. The maximum allowable wing loading due to internal fuel storage must also be considered. The average wing weight for a light aircraft is approximately 2.5 $\frac{lbf}{ft^2}$ [19]. Fuel can also be stored under the wings, similar to weapon placement, but the weight of external tanks would be a drawback. Storage within the fuselage is still being considered, but due to safety requirements and survivability, this is a last resort option. A pump fuel system will be utilized for fuel transportation due to low-mounted wings. The amount of fuel needed to satisfy both mission requirements will ultimately decide how much internal fuel storage will be necessary leading to an estimated amount of external fuel required.

C. Detailed Aerodynamic Analysis

1. Airfoil Selection

In evaluating main wing airfoils for the KA-Ranger, the bounds of performance were set by two reference airfoils. These airfoils are the NACA 63-415, shown as a dashed dark green line in Fig. 6, and the NACA 6716, shown as a dashed red line in figure 5. The NACA 63-415 is the airfoil on the A29 and the NACA 6716 is the airfoil on the A10. The design airfoils were found using the XFoil function embedded in the xflr5 program, and the results were plotted in flow5. All performance curves were based on a Mach of 0.33 and a high Reynolds number, typically between one million and ten million. Three airfoils were chosen for further analysis. These airfoils are the NACA 4416, 3418, and 6518. An ideal airfoil for the mission was envisioned to have a lift curve that was within the bounds set by the reference airfoils as well as having a high stall angle and gradual stall. The ideal airfoil also had high lift to drag ratios at low angles of attack with a low to moderate pitching moment.
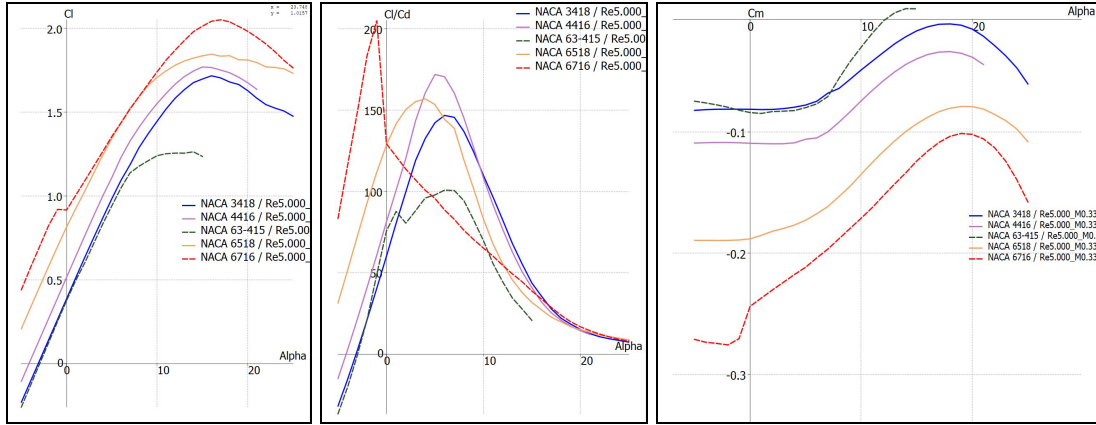
Fig. 6a: C_l **Fig. 6b:** C_l/C_d **Fig. 6c:** C_m

As seen in the comparison of airfoil lift curves in Fig. 6a, all three of the candidate airfoils lie inside the bounds as given by the A10 (63-415, dark green) A29 (6716, red). The NACA 6518 (orange) has very good stall characteristics, with a rather flat stall at a respectable angle. The NACA 3418 (blue) is comparable to the NACA 63-415 (dark green), especially at an angle of attack of zero, however it stalls later than the 63-415, and while not as favourably as the NACA 6518, it is not an abrupt stall. The NACA 4416 (purple) sits in the middle, with higher lift, but not as favourable stall characteristics. Fig. 6b shows the performance in terms of the lift to drag ratios of the potential airfoils versus angle of attack. This metric was chosen to represent the performance of the airfoil because it will directly affect the KA-Ranger's range. The curve corresponding to endurance is very similar to Fig. 6b and will not be discussed for brevity. In Fig. 6b, we see that the best performing potential airfoil is the NACA 6518, with a curve that is shifted left of the other candidates providing very strong performance at low angles of attack. Fig. 6c shows the moment curve of the potential airfoils. From the comparison of moment coefficients in Fig. 6c, we can see that the price paid for the impressive lift, performance, and stall of the NACA 6518 is in its pitching moment; this massive moment is only eclipsed by the reference upper bound NACA 6716. The NACA 4416 and NACA 3418 lie close to each other, with the 3418 inducing a weaker moment at low angles of attack than the reference lower bound.

With this in mind, the NACA 3418 was chosen to be the KA-Ranger's prime airfoil, with the NACA 4416 and NACA 6718 being first and second alternate, respectively. The 3418 was chosen due to its similarity to the NACA 63-415 as the KA-Ranger is more similar to the A29 than the A10. Further, the NACA 3418 was chosen over the other candidates primarily because of its favourable stall characteristics, and weak moment. This should allow the KA-Ranger to have a smaller horizontal stabilizer, reducing the whole-aircraft drag. Further analysis continues into the application of these airfoil choices into the whole wing.

2. High Lift Devices

Maximizing lift and efficiency while minimizing drag effects on the aircraft suggests the use of high lift devices to attain desired performance characteristics. In particular, increasing the surface area and camber of the wing while in the loiter phase of the flight envelope will allow for a more effective weapons deployment as the stall speed is reduced. In order to attain a reduction of stall speed, fowler flaps were initially researched as they provide suitable conditions for takeoff and landing [20]. The implementation of high lift devices will allow us to optimise the main wing for performance at cruise. Further aerodynamic analysis of KA-Ranger will result in a more accurate lift requirement for designing high lift devices.

D. Performance Analysis

A MATLAB code was written to analyze the performance of the KA-Ranger. The baseline code estimates the power available, power required, service ceiling, range, and endurance of the design. The process began by choosing the PT6A-68B engine, which has an uninstalled ESHP of 1900 hp [21]. This number was then reduced by an installation factor of 15% to yield an installed ESHP of 1615 hp. This engine can obtain a BSFC of 0.54 1bf/hp-hr at maximum thrust using Jet A-1 fuel [22]. From researching propulsive efficiencies, the team decided to adjust the available power by a propeller efficiency for 0.92 [23]. The approximate C_{DO} was found to be 0.0184

based on similar aircraft [19]. The remaining inputs were the aspect ratio of 6.5, wing area of 250 ft^2, and total weight of 12,000 lbf were also assumed.

The power available and power required curves are first calculated using Eqs. 1 and 2 where C_L and C_D are calculated in Eqs. 3 and 4 and Oswald efficiency factor is found from Eq. 5 [19]. The power curves at sea level and the minimums for the design and ferry missions, 10,000 ft and 18,000 ft, are shown in Fig. 7.

$$P_A = ESHP \cdot \eta_p \cdot \frac{\rho_{alt}}{\rho_{SL}} \tag{1}$$

$$P_R = \frac{W_{total} \cdot V_\infty}{C_L/C_D} \tag{2}$$

$$C_L = \frac{W_{total}}{\frac{1}{2} \cdot \rho_{alt} \cdot V_\infty^2 \cdot S_w} \tag{3}$$

$$C_D = C_{Do} + \frac{C_L{}^2}{\pi \cdot e \cdot AR} \tag{4}$$

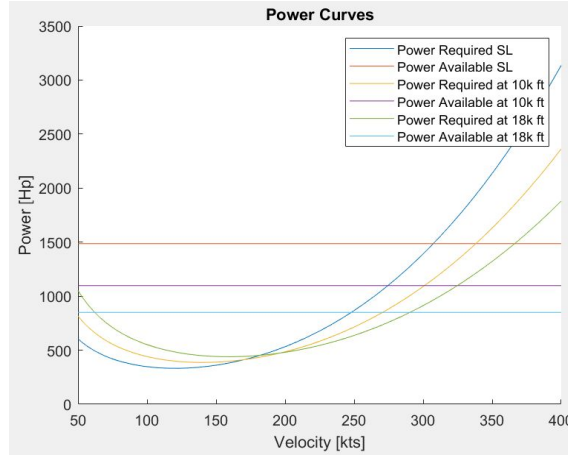$$e = 1.78 \cdot (1 - 0.045 \cdot AR^{0.68}) - 0.64 \tag{5}$$

Fig. 7 Plots of Power Available and Required Curves at Various Altitudes

The difference between the power available and required curves is related to the rate of climb by Eq.6 [19].

$$P_A - P_R = W_{total} \cdot ROC \tag{6}$$

The program iterates through different air densities, calculating the difference between the power available and power required, until the current value is less than the minimum required for 100 ft/min climb. The altitude is then interpolated from known air density and altitude data. The final value came out to be a service ceiling of 29,323 ft, which is less than 700 ft below the requirements. By altering some of the inputs, it was found that weight reduction, increased wing area, increased aspect ratio, and decreased C_{DO} are all means of increasing the service ceiling. However, it should be noted that some parameters are inversely proportional, such as increased wing area also increasing the weight of the aircraft. To refine the design, these parameters will be altered with consideration to structures, stability, and aerodynamics consequences until a more optimal design is found.

The baseline design's range and endurance were calculated as a function of flight speed using Eqs. 7 and 8 [19].

$$Range = \frac{\eta_p}{BSFC} \cdot \frac{C_L}{C_D} \cdot log(\frac{W_{total}}{W_{total} - W_{fuel}}) \tag{7}$$

$$Endurance = \frac{\eta_p}{BSFC} \cdot \frac{C_L{}^{3/2}}{C_D} \cdot \sqrt{2 \cdot \rho_{alt} \cdot S_w} \cdot ((W_{total} - W_{fuel})^{-0.5} - W_{total}^{-0.5}) \tag{8}$$

These curves are plotted in Fig. 8 for sea level, the design mission cruise altitude of 10,000 ft, and the ferry mission altitude of 18,000 ft. The maximum range at sea level was found to be 2458 nmi at 158 knots while the maximum endurance was at 19.1 hours at 120 kts. At the design mission cruise of 10,000 ft, the maximum range

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was found to be 2458 nmi at 185 knots while the maximum endurance was 16.4 hours at 140 kts. Meanwhile, at the ferry mission cruise of 18,000 ft, the maximum range was found to be 2458 nmi at 210 kts while the maximum endurance was 14.4 hours at 159 kts.
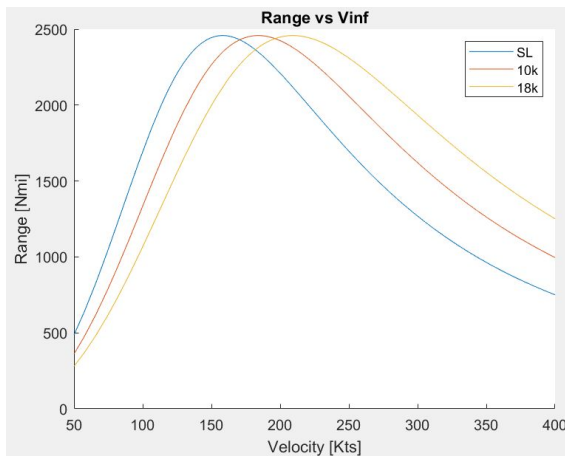

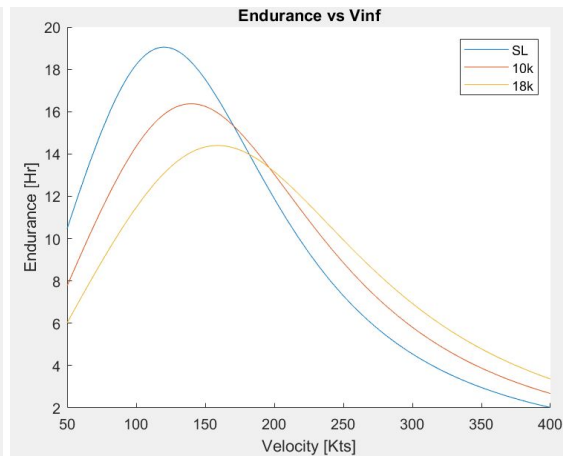**Fig. 8a Plots of Range versus Velocity**   **Fig. 8b Plots of Endurance versus Velocity**

VII. Conclusion and Next Steps

The culmination of research of similar mission aircraft has led to the initial concept design for the KA-Ranger. By analyzing the characteristics of different aircraft types defined by their engine configuration, it was determined that the turboprop would best suit the design constraints for the close air support aircraft launching from an austere field. By further analyzing the turboprop class of aircraft, the maximum takeoff weight and aspect ratio were chosen for the KA-Ranger. From there, several of the remaining major aircraft dimensions were determined and calculated, including the wing area, wing span, wing chord, and aircraft length. While these values have been chosen, they are flexible to change as further detailed design is completed.

Beginning the preliminary design of the KA-Ranger, several subsystems of the aircraft were designed with greater detail. The aircraft material was selected as Aluminum-2024 for the load bearing structures and Aluminum-6061 for the outer surfaces. The placement and configuration of the weapon systems were arranged for the best stability and drag performance. The fuel system was designed to be favorable for aircraft stability as the fuel is burned. The Jet A-1 fuel will allow for an easier distribution by the military forces using the KA-Ranger and will be stored in the wings. If more fuel is needed, external fuel tanks will be added to the wings, and possible within the fuselage. A detailed analysis of the wing airfoil geometry resulted in the selection of the NACA 3418 airfoil. Performance calculations provided values for specific fuel consumption, maximum range, maximum endurance, and the service ceiling for the KA-Ranger.

Moving forward, the currently designed subsystems will be expanded upon as required and the remaining subsystems of the aircraft will need to be designed and analyzed in greater detail. This will begin with an analysis of component weights in order to determine the empty weight and the center of gravity of the aircraft with no fuel or armaments. This will allow for the examination of the KA-Ranger's stability characteristics. Having developed the structure of the wing and the fuselage, the lift and moment coefficients can be calculated and an aerodynamic center for the aircraft can be determined. Comparing this to the center of gravity, both empty and fully armed, the longitudinal stability can be analyzed. If the aircraft doesn't have a positive static margin then the aircraft will need to be reconfigured, likely by shifting the center of gravity location forward on the aircraft. With the placement of the weapon systems determined, the drag of the airplane can be further examined. The aircraft structure will undergo both parasite drag and induced drag. The induced drag will be determined from the geometry of the aircraft and is a product of the wing producing lift. The parasite drag is a combination of the profile drag of the aircraft shape and the drag caused by miscellaneous components such as control surfaces, weapon placements, and landing gear. Additionally, a detailed analysis for the engine will be conducted for the current industry turboprop that is chosen for the aircraft. This will include a power curve graph up to the service ceiling, as well as an analysis of the fuel consumption efficiency to determine the amount of fuel needed for the design missions. The biggest obstacle will be weight management. The subsystems will need to be optimized for the lowest possible weight while not sacrificing the required performance specifications.

The KA-Ranger is in the intermediate stages of its preliminary design and requires more design work to become a functioning mission capable aircraft. The turboprop aircraft will continue to be designed far beyond the disciplines listed above. The later stages of the conceptual design will be reserved for system optimization to better meet the standards that have been designated for the aircraft. As each design decision is made, the aircraft will be tested to determine that it continues to meet or exceed the design criteria that have been set by the customer and the Kestrel Aeronautics team.

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