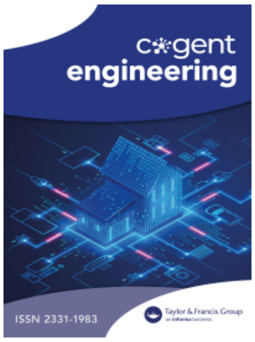


Taylor & Francis
Taylor & Francis Group

Cogent Engineering

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaen20

Cost effectiveness and feasibility considerations on the design of mini-UAVs for balloon takedown. Part 2: Aircraft design approach selection

Luca Piancastelli, Christian Leon-Cardenas, Eugenio Pezzuti & Merve Sali

To cite this article: Luca Piancastelli, Christian Leon-Cardenas, Eugenio Pezzuti & Merve Sali (2023) Cost effectiveness and feasibility considerations on the design of mini-UAVs for balloon takedown. Part 2: Aircraft design approach selection, Cogent Engineering, 10:2, 2257958, DOI: 10.1080/23311916.2023.2257958

To link to this article: https://doi.org/10.1080/23311916.2023.2257958

Piancastelli et al., *Cogent Engineering* (2023), 10: 2257958
https://doi.org/10.1080/23311916.2023.2257958

Received: 17 May 2023
Accepted: 07 September 2023

*Corresponding author: Christian Leon-Cardenas,
E-mail: christian.leon2@unibo.it

Reviewing editor:
D T Pham, School of Mechanical Engineering, University of Birmingham, United Kingdom

Additional information is available at the end of the article

MECHANICAL ENGINEERING | RESEARCH ARTICLE

Cost effectiveness and feasibility considerations on the design of mini-UAVs for balloon takedown. Part 2: Aircraft design approach selection

Luca Piancastelli[1], Christian Leon-Cardenas[1]*, Eugenio Pezzuti[2] and Merve Sali[1]

Abstract: The widespread availability of cheap, mass-produced balloons puts a strain on the financial and manufacturing capacities of most aerial interception systems. In the past, high-altitude guided balloons that were between 65,000 ft (19.812 m) and 95,000 ft (27.432 m) in the air have been destroyed successfully by modifying bombers and airplanes to use a high-power laser system. High Altitude Long Endurance (HALE) Unmanned Aerial Vehicles (UAV) with laser systems are also on the market. Nevertheless, the cost to produce and maintain these systems is extremely high. A very cost-effective alternative is to create a mini—Unmanned Aerial Vehicle Interceptor (UAVI) that can intercept and bring down a balloon at a height of 65,000 ft (19.812 m) and has a Maximum Take Off Weight (MTOW) under 100 kg. To enable mass production, the UAVI should make use of readily available components and a simplified carbon fibre reinforced polymers (CFRP) structure. The vehicle also has a commercial microjet engine with an appropriate air intake and nozzle. This paper introduces the design of a cost effective UAVI to minimize the cost this analysis starts from existing, off-the-shelf Radio Commanded (RC) models. An ad-hoc design was then compared.

Subjects: Mechanical Engineering Design; Testing; Aerospace Engineering; Design; Electronic Devices & Materials; Engineering Economics; Technology; Transport & Vehicle Engineering

Keywords: anti-missile systems; UAV; re-usable; cost-effective

1. Introduction

High altitude Sky balloons and long-duration balloons have several characteristics that make them a treat for national security. One of the most important capabilities is the wide-area surveillance. Because these balloons can fly at high altitudes (over 20 km) (Alam et al., 2023; Dai et al., 2012). And they can manage a large-scale surveillance over both land and water. Thus, they are ideal for gathering information, military operations. Due to the long periods of stay in the air, Sky Balloons can manage ongoing surveillance. This ongoing surveillance is challenging for the militaries because of the traction capabilities of balloons while defending themselves. However, these balloons can transport large capacity cargo, such as cameras, signal equipment for security intelligence and other sensors. The large payload capacity makes them more probable for an extensive information gathering. Another challenging issue about Sky balloons is that they are able to avoid from conventional air defence systems due to their capability of flying at high altitudes. These capabilities make them privilege for national security. To deal with this threat, countries can follow a versatile strategy such as investments in cutting-edge air defence systems, boosted intelligence, surveillance, and reconnaissance capabilities. Hypersonic missiles, hordes of intelligent drones, directed-energy weapons, and artificial intelligence are seen as a main issue in air combat in the twenty-first century (Ahmed & Qin, 2020; Pope et al., 2021; Tumbarska, 2021; Weinberg, 2021). Old fashion balloons may play a crucial role in combats. Combination of old and new technologies in the air littoral can be used as attackers. Those kinds of attackers, including man-portable air defence systems, radar-guided anti-aircraft artillery, cruise missiles, dual-use drone technologies, and loitering munitions, are located below 15,000 ft (4.572 km) which keeps the airspace attempted (Col Mandeep Singh, 2022). Using these spy balloons due to their high-altitude property is not a recent invention. The Japanese flammable balloons launched into the jet stream During World War II. Moreover, the US achieved several spy balloon missions over the USSR in the 1950s and currently they tested the use of mass surveillance balloons all over the country. Today, technological developments and business methods combinations makes the artificial intelligence-guided balloons possible to reach in the space littoral for scientific research internet communications, and ultrahigh-resolution imagery. The space littoral was used in 2018 in the official newspaper belongs to Liberation Army of Chinese People and thought as a new type of battlefield in modern warfare (Grieco, 2018). Chinese spy balloon does not compel an air superiority on American airspace, but it provides a transition on airspace and thus other unprojected outcomes have the possibility to happen. Multiple drones or missiles could be launched from high altitude balloons to attack radar sites and air bases. In 2018, the Chinese military performed a search with high-altitude balloon carrying hypersonic missiles and in 2020, they focused on the concept about near-space weapons. Because they think that high altitude balloons have more advantage than traditional aircraft due to their advantage in height, much larger reconnaissance field of view and strike coverage. Especially the near-space weapons are highly manoeuvrable and effective for stealthy ground strikes. Besides, radars or infrared detection equipment are highly unable to detect them. These balloons could be a persistent threat to airborne systems, including aircraft, operating in the clear skies below them because they have a very small radar cross section, making them harder to spot and take out. These balloons are hard to detect and eliminate due to their small radar cross section even in the clear skies. The US was unable to identify Chinese spy balloons before invading into American airspace. Thus, in 2023 North American Aerospace Defence Command (NORAD) enlarged the filter for slow moving objects to be able to detect more objects. But, still, High-altitude balloons will still present a challenge even if they are discovered. Capability of tracking down and targeting enemy air defence makes them a big threat (Leventopoulos, 2019; LTC Gregory P. Shipper, 2020; Maurer, 2021). In several previous research, the idea has been argued that the balloons can be used for inducing and organizing defence system of enemy air. Also, it is probable to create suitable conditions for the electronic reconnaissance applications while being used for early warning detection on defence system. In case of using high number of balloons, the technology such as missiles and strategies will be insufficient to defend. Still, high-altitude balloons are one of the efficient ways to takedown enemy. Even if all the calculations were made by using the IS (international system), the altitudes will be expressed also in feet due to the normal use in the aeronautic world. In the first paragraphs of this second part of the paper we will explain the aim of this work, making a summary of the first part of this paper. We will then do a review of the most promising designs and we will find the best solution.

Aim of this paper is to find a way to takedown large numbers lighter-than-air aerial vehicles economically. It is therefore crucial to design specialized aerial weapons that will cost less than the balloon even in their most economical version. The cost of the most economical “spy” lighter-than-air vehicle with a high-resolution camera, a reliable communication and navigation package is in the order of magnitude of 3,000 USD. The single “balloon killer” mission should cost a similar amount of money. For this reason, missiles are too expensive. Only a very small aircraft with a gun can keep the costs so low.

2. Materials and methods

2.1. Summary of cost effectiveness and feasibility considerations on the design of mini-UAVs for balloon takedown. Part 1: weapons and mission

In the first chapter of this study which is named as Part I: weapons and mission, it was found that medium altitude 36,000 ft (10.973 km) airplanes equipped with high power lasers have already been developed to deal with high altitude objects. It is also said that High Altitude Long Endurance (HALE – 65,000 ft (19.812 km) Unmanned Aerial Vehicles (UAV) equipped with low power lasers are also available. Both these systems are quite expensive to purchase and operate. Several aircraft would be needed to deal with the large number of balloons. For this reason, the Authors hypothesized the use of small UAV Interceptors (UAVI) able to carry 84 mm recoilless cannon(s) with airburst ammunition up to 95,000 ft (27.432 km). The use of cannon was found to be the most cost-effective solution because missiles are too expensive and machine guns are ineffective. This "small" cannon is commercially available with a weight of 10 kg (ammunition included) and an overall length of 950 mm. Advanced jet engines from the RC airplane market are also available with a static thrust up to 1,100 N and a thrust to weight ration around 100 [N/kg]. With a properly designed air intake and nozzle, these propulsion systems reach 65000 ft (19.812 km) with a residual thrust of 10% the static value if the vehicle travels at 0.9 M. at 95,000 ft (27.432 km) the thrust is 3% at 0.9 M. At higher speed (1.6 M) the thrust reaches 10% at 95,000 ft (27.432 km). It is not convenient to climb at partial load. In fact, the jet engine has better efficiency at full throttle, and it is highly dubious that over 36,000 ft (10.973 km) the engine would have throttled capability (Das et al., 2020; Wei et al., 2020). These jet engines come with a Full Authority Digital Electronic Control (FADEC) for starting, fuel dousing and flooding control. Several control, navigation and transmission systems are sufficiently small to be installed in a very small UAVI. Miniaturized sensors are also available. For real time radio control, the maximum practical flight range is 320 km. Even if the UAVI may fly on autopilot, the weapon necessitates fire authorization for safety reasons. In addition, the UAVI may transit in Air Traffic Controlled (ATC) areas where a communication rely on system is necessary. For this reason, a transponder should also be installed. The mission would start from a ground station, a small van, or an airplane. For this reason, the maximum wingspan is limited to 3 m when using a Lockheed C130. The typical mission would start with a rapid check made with the aid of an Electronic On-Board Diagnosis System (EOBD). The operator would then feed the necessary data in Flight Control System (FCS) of the UAVI's Auto Flight Control System (AFCS). The data will include the flight plan with the estimated position of the target (enemy balloon). After a drop, a ramp, or a catapult-assisted take-off, the UAVI will make a controlled climb in the shortest time possible. Hopefully, with the help of the on-board sensors or guided from the ground station, the UAVI would detect the balloon at a distance of a few kilometres. At this point, it will inquire the ground station for the authorization to engage and takedown the enemy. The laser rangefinder and the ballistic software will determine the optimum distance to fire (around 500 m) and the on-board computer will program the airburst ammunition. When the cannon is fired, a large blast will take place in the rear of the UAVI, and the supersonic wave of the shell will invent the small airplane. In addition, the bore and nozzle fairing of the cannon will collapse, with a sudden additional drag to the UAVI. For this reason, it is possible that the UAVI would lose control after firing. However, the balloons fly at very high altitude, and for this reason, there is plenty of time to recover attitude and to restart the engine if necessary. Presumably, engine restart will take place below 24,000 ft (7.315 km). The UAVI will then meet an arresting gear of a rescue station and will remain suspended to the wire. If everything goes as planned, the UAVI will be ready for a new mission after refuelling and recharging. It is essential to keep the cost of the UAVI as low as possible. In fact, due to the low range of the UAVI, several weapon systems are necessary to protect the national airspace. Theoretically, it is also possible to rescue the UAVI with an airplane. Technology is available, but the additional costs are huge.

For the aerodynamic behaviour of the vehicles with the firing system can be analysed with a flying test. However, due to the extremely high speed (nearly sonic or supersonic) of the airplane, the shock waves of the venting portion of the weapon's propellant gas to the rear of the tube do not reach the airplane. This fact is due to fact that the rear venting nozzle is positioned in the rear of the airplane, over the jet nozzle. The projectile does not have a sabot, so the shell will leave the cannon mouth at supersonic speed. The supersonic wake of the projectile will invest the airplane, but the mass of the shell is less than 1/10 of the UAV mass and the shell shock wave is approximately aligned to the one of the airplanes. The recoil is very mild (far less than the one of a rifle) therefore the momentum interaction with the airplane is extremely mild.

2.2. Airframe and aerodynamic design

To enable mass production, cost-cutting measures should be taken. As a result, at least for the initial evaluations, an existing design is utilized. There is a market for Radio-Controlled (RC) fighter models. The basic design of two CFRP (Carbon Fiber Reinforced Plastic) shells with aerodynamic control surfaces, servos, and drogue parachute is retained, despite the need to redesign the airfoil and air intake to consider for the drastically different Reynolds numbers (Xia et al., 2021). The "military version" could be built with the best off-the-shelf components. The UAVI will not have hydraulically actuated legs doors, wheels, and brakes. An arresting hook will meet the arresting gear and the UAVI should remain suspended to the wire. The servo-operated hook can be simply spring-loaded. The additional fuel tank(s) will not significantly increase the overall weight. To account for altitude and raise fuel temperature, compressor air from the jet engine will pressurize the fuel tanks. The RC model market also offers AFCS hardware and software (Salari et al., 2020). High-quality parts with accelerometers, gravity sensors, and a low-quality inertia platform are sufficient for controlling even shaky aerial vehicles. A high-precision laser platform that can either replace or supplement the Global Positioning System (GPS), depending on the mission. Also needed is a laser rangefinder for programming the airburst round. Several scaled down versions of popular airplanes are available on the RC market. Scaled aircraft models have been used to create and test new aircraft designs since the Wright Flyer. On the other hand, fixed-wing aircraft are preferred for this study. Because rotary wings are not suitable for use at very high altitudes (Bian et al., 2021; Gökbel & Ersoy, 2021) to the size of rotors that would have been required. Lighter to air aircraft lack of the necessary manoeuvrability. These scaled models were frequently used to simulate the dynamics and aerodynamics of developing aircraft safely and efficiently. Many authors argue that testing and scaling an aircraft alone is insufficient to accurately simulate full-scale airplane motions due to the significant changes in dynamics and aerodynamics caused by weight and scale (He et al., 2021; Raju Kulkarni et al., 2022). This implies that before any data can be used, correction factors must be applied. Currently, commercial transport stall models are being improved using dynamically scaled vehicles through the NASA Airborne Subscale Transport Aircraft Research (AirSTAR) Program (Cunningham et al., 2008; Murch, 2008). In the past, the NASA Stall/Spin Research Program for General Aviation (GA) has been studied using dynamically scaled models. Downsized aircraft, however, are unable to faithfully reproduce the flying characteristics of full-scale aircraft because they are rarely dynamically scaled. Table 1 lists a few dynamic scaling variables. To calculate the ideal mass scaling for the downsized aircraft, the geometrical Scale Factor (SF) and the Dynamic Factor (DF) can be used. "ρ" represents the mass density (kg/m^3) (Raju Kulkarni et al., 2022).

Table 1. Dynamically scaling requirements

Parameter	Scaling factor	Compliance (F16–1:6) at 65,000 ft (19.812 km)
Wing Area	SF^2	100%
Mean Aerodynamic Cord	SF	100%
Volume	SF^3	100%
Mass	SF^3DF	100%
Moment of Inertia	SF^5DF	100%

$$DF = \frac{\rho_{\mathrm{UAVI}}}{\rho_{\mathrm{full\_scalel}}} \tag{1}$$

$$SF = \frac{L_{\mathrm{UAVI}}}{L_{\mathrm{full\_scale}}} \tag{2}$$

$$\frac{M_{\mathrm{UAVI}}}{M_{\mathrm{full\_scale}}} = \frac{\rho_{\mathrm{UAVI}}}{\rho_{\mathrm{full\_scale}}} \frac{V_{\mathrm{UAVI}}}{V_{\mathrm{full\_scale}}} = DF \times SF^3 \tag{3}$$

The Lengths (L) are scaled by SF that goes with SF^2 for surfaces and SF^3 for Volumes (V). The reference mass density of the full-scale airplane $\rho_{\mathrm{full\_scale}}$ (Equation 1) is the mass density at ceiling. The ρ_{UAVI} is the mass density at reference altitude for the UAVI (65000 ft-19.812 km). The dynamic equivalence between the mass of the UAVI (M_{uavi}) and the mass of the full-scale airplane ($M_{\mathrm{full\_scale}}$) goes with equation (Equation 3).

Scaling down commercial airplanes is possible, but manoeuvrability problems arise. Larger control surfaces would be required at high altitude, with a large redesign of the airplanes. Table 1 displays the specifications for dynamically scaling an aircraft. The last column shows the compliance of the scaled down (1:6) F16 UAVI. The Wing Area, Mean Aerodynamic Cord, and Volume are correctly scaled in a 1:6 downsized UAVI, the Mass and Volume match only at 65,000 ft (19.812 km). The mass and inertia of a 1:6 “F16 downsized” UAVI will be excessive at higher altitudes (Noël et al., 2013). As a result, the UAVI’s wing loading, and inertia will be too low at altitudes lower than 65,000 ft (19.812 km). Because of this, the UAVI will be able to reach and manoeuvre better than the original fighter up to this altitude (Ibrahim & Noura, 2020; Liu et al., 2019). From 65,000 ft (19.812 km) to 90,000 ft (27.432 km) the manoeuvrability of the airplane worsens, and the control surfaces should be adequately integrated to retain a minimum level of stability with proper control from the FCS. Luckily, the balloon is a near static target and the speed should be higher than 0.8 M during the climb phase (Seshagiri & Promtun, 2008). Moreover, maximum speed is limited by fixed air intake optimum performance, in this case Mach 1.6. The take of length is 4 m with a ski jump or 9 m horizontal run and jettisonable three-wheel trolley. A good alternative is a pneumatic or an electromagnetic catapult.

2.3. Advanced jet models available on the RC market and reliability of the parts

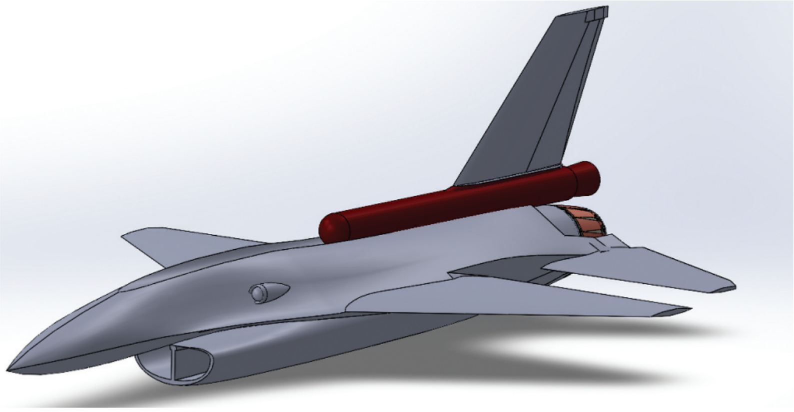
RC models with propeller are not suitable for use up to 95,000 ft (27,432 m) (Shen & Ochiai, 2021). Jet models can be modified for the task. It is vital that the attack takes place on the upper part of the lighter-than-air aerial vehicles. In fact, helium is lighter than air and will easily pass through holes in the upper part of the envelope to reach higher altitudes. Holes on the side would be far less effective. Holes in the bottom will simply let the air enter the envelope from below and the helium will remain still trapped inside. It is essential that the attack takes place with the UAVI higher or at least at the same level of the balloon. Several jet RC models are available on the market. Many of them are scaled down fighters. A few of them are made with carbon fibre. The most common models are 1:4,1:5,1:6 scaled down RC models of the General Dynamics F16, Lockheed F104, McDonnell Douglas F15, Grumman F-14, Lockheed SR-71, Sukhoi Su-35, Mikoyan-Gurevich MiG-29. Scaled down models of the large bombers and airliners are more critical for handling and structural integrity (Dantsker et al., 2023). A few of these models use Arduino platforms to make the flight control easier and to rescue the airplane it the radio-control limits are exceeded. High quality servos and radio control are common. Dual redundancy of radio control is also present to address servo reliability problems. Even if airfoils, jet engines and air intakes must be redesigned, the availability of a flying commercial model reduces the development costs. As demonstrated in Part I of this paper, speed is necessary to achieve the necessary thrust to reach 95,000 ft (27,432 m). To reach high subsonic or supersonic speed with modified commercial microjet engines, small models should be used. For this reason, the 1:6 scale is the best. The reliability and availability problems will be addressed in the Part III of this paper along with the cooling problems.

2.4. First design iteration: the 1:6 F16 balloon killer

The first iteration of the design is a smaller F16. A scaled-down version of the General Dynamics F16 (Shao et al., 2022) belongs to one of the families of RC models that is the most widely accessible. For our UAVI, this aircraft matches the dynamic behaviour of the original F16 at 65,000 ft (19.812 km) (Table 1). Additionally, at high speeds, the F16 design is not very efficient. The need for a different Reynolds number necessitates redesigning the air intake of the jet engine. 0.3 Mach is the maximum allowed speed at the engine face (Hasan et al., 2022). The ceiling density altitude for the original F16 is 50,000 ft (15.240 km) ISA (International Standard Atmosphere. This is the value used for the DF coefficient. The cockpit and landing gear of the F16 1:6 RC model can be easily removed, and the original, small, light jet engine can be swapped out for a much heavier 1,100 N unit to obtain a true, high altitude UAVI. A larger internal fuel tank and a spring-loaded arrest hook complete the basic structure. The sensors are completed by a set of at least two micro cameras, a GPS receiver, an anemometer, an altimeter, an attitude indicator, and a laser inertia platform. A data transmission package, a transponder and a laser rangefinder are also necessary. Running on a microcomputer, the AFCS would control the UAVI. A redundancy software backup system should be implemented, and this computer should be duplicated. The brains of the AFCS in contemporary RC models are the Flight Management Guidance Computer (FMGC) or Flight Management Guidance System (FMGS). Some manufacturers also refer to it as the Autopilot Flight Director System (AFDS). The small computer already has GPS, inertial reference units, and a flight control computer. The servos connected to this computer will operate the UAVIs. JetCat Company that makes jet engines typically offers the Full Authority Digital Engine Control (FADEC), which connects to the AFCS. Given how unreliable the GPS is, adding a laser inertia platform is practical. Our air data system is only equipped with an altimeter, an attitude indicator and two anemometers. Before take-off, the ground crew can operate the OBDS (On Board Diagnosis System) and set up the Flight Management System (FMS) using a USB port and Multifunctional Control Display Unit (MCDU). Two issues need to be resolved. Radio Frequency (RF) and Electro Magnetic Interference (EMI) shielding come first. With modern technology, it is quite simple to create this kind of shielding. The temperature control of the servos, sensors, and hardware is much more difficult to manage at high altitudes because the extremely rarefied air does not offer much cooling. Dedicated air intake and a fuel-cooled sink are two alternatives that should be considered. Figure 1 shows a possible configuration for the UAVI.

The main cannon should have exhaust in the back of the airplane to avoid the blast damages the UAVI. It may be possible to install a collapsible tail cone on the cannon exhaust, but this option should be carefully analysed. A collapsible nose can be installed on the bore to improve the aerodynamic performance during the climb. The airplane belly should be left clear for the arresting hook. Therefore, the position of the weapon is heavily constrained. A few concerns remain. The weapon over the jet engine is far from being ideal, should something go wrong with the jet, the cannon round that is locked in front of the jet nozzle can detonate. A proper ceramic-

Figure 1. 1:6 scaled F16- balloon killer (schematic).



fiber protection should be installed to limit this risk. The second is that the 10 kg cannon, with the 3.1 kg High Explosive (HE) round locked in the rear, is positioned in the tail over the already heavy jet engine (11 kg approx.). The Center of Gravity (CG) of the airplane is shifted rearwards from the original RC model. It is possible that a ballast is needed on the nose to keep the CG within reasonable limits. Cl-Cd curves of scaled-down models of the original F16 are available in literature (Fox, 1993) (Figure 2). In Figure 2, black line shows the result when 0.9 Mach and red line shows the result when 1.6 Mach.

Table 2 summarizes the data of the F16 and its UAVI replica.

Figure 3 is drawn by using the curves from the first part of this paper and the data from Table 2. The UAVI flying at 0.9 M will reach the required altitude 95,000 ft (27.432 km) with reduced manoeuvrability from 65,000 ft (19.812 km) to 95,000 ft (27.432 km). The UAVI has not supersonic capability at any altitude. The blue curve of Figure 3 is calculated with Equations (4–5) and the curves of Figure 2. The ν [m/s] is the airplane speed and ρ is the ISA altitude density [kg/m^3]. Equation 4 shows lift coefficient formula which is equal to the lift ($m_r g$) divided by fluid density, fluid velocity (v_v) and the wing area (w_{area}). D is the airplane drag force [N]. Trimming is not considered in this preliminary evaluation. g is the acceleration of gravity. C_D is drag coefficient.

$$C_L = \frac{2m_r g}{w_{area}\rho v_v^2} \tag{4}$$

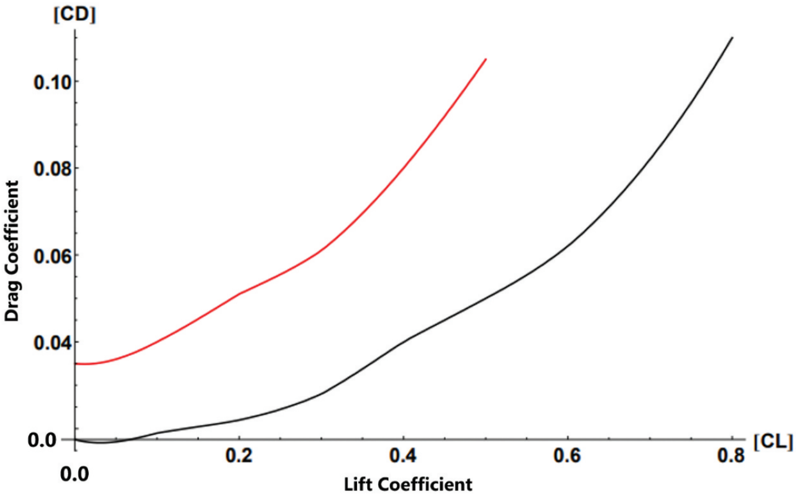
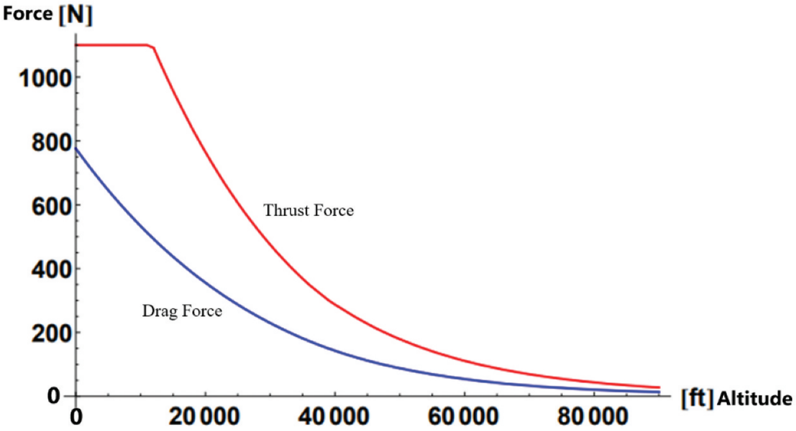


Figure 2. Lift coefficient (Cl)-drag coefficient (Cd) diagram of F16.

Table 2. Full scale F16 and UAVI basic data (Figure 1)

Parameter	Original F16	F16 1:6
Length (m)	15.06	2.51
Wingspan (m)	9.96	1.66
Wing Area (Warea) (m2)	28	0.774
MTOW (kg)	19187	52.46
Half Internal Fuel Mass (kg)	666	6.23
Reference mass mr (kg)	18521	42
Dynamic similitude	-	100%
Re at .9 Mach and 12 km	1.445 107	2.28 106
Maximum static thrust T [N]	-	1.100
Maximum speed [M]	2	0.9

Figure 3. Force – altitude graph of 1:6 scaled F16 at 0.9 M.



$$D = \frac{1}{2} C_D \rho v_v^2 w_{area} \tag{5}$$

From the red curve of the Thrust T [N] and the blue curve of the Drag D [N], it is possible to calculate the climb angle (α) (Eq. 6) and the Rate of Climb ROC [m/s[1]] (Eq. 7) at any density altitude ρ. The rate of climb (ROC) is an aircraft's vertical speed, that is the positive or negative rate of altitude change with respect to time. Equation 7 shows the relation between the climb angle with ROC.

$$\propto = \sin^{-1}\frac{T - D}{m_r g} \tag{6}$$

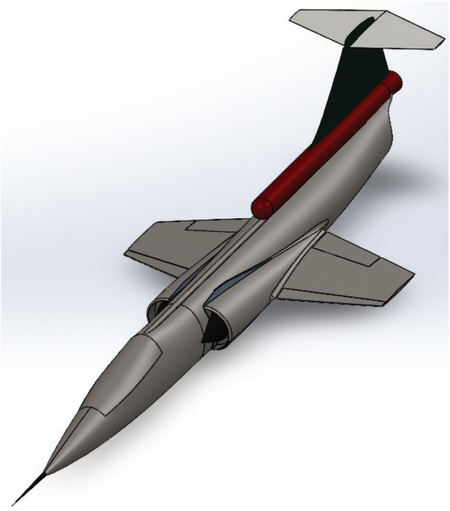
$$ROC = v_v \sin \propto \tag{7}$$

Besides the CG problems, the F16 design seems not to be ideal for a climber. The F104 fighter was much better for climbing, being essentially a missile with small wings. The second iteration will therefore use a scaled down (1:6) F104 model (Figure 4).

2.5. Second design iteration: the F104–1:6 - single cannon

The F104's reference density altitude is 58,000 ft (17.678 km) ISA. Schematic scaled F104 is shown in Figure 4

Figure 4. 1:6 scaled F104 - single cannon design (schematic).



The downsized UAVI based on the F104 is lighter and performs better at altitude than the F16 1:6 UAVI. It seems to have supersonic capability at 37,000 ft (11.277 km) − 1.6 M. The F104 based UAVI (Figure 6) has the same CG problem as the F16 based UAVI with the additional possibility to lengthen the fuselage in front of the wings or to move the wings rearwards. An additional section of the fuselage in front of the air intakes would have the additional benefit of increasing the internal fuel capacity with little influence of the overall drag of the UAVI. The main problem of this solution is that, in case of total loss of control on cannon fire, the airplane may finish in a deep stall. It is what happened in the famous accident of the Lockheed NF104A (USAF 56–0762) (Tony Landis, 2021). The only solution is to use the emergency parachute. In the UAVI the emergency parachute is conceived to reduce damage to third parties in case of serious failure. Therefore, if the parachute is deployed, the UAVI is lost. Another issue is the overall reliability of a single round, single cannon airplane. The mission fails also in case of single weapon malfunction.

2.6. Third design iteration: the F104 1:6 - twin cannons

The data of the F104-downscaled-double cannon UAVI are shown in Table 3. Also, schematic picture of scale F104 has shown in Figure 5. The F104’s reference density altitude is the same as the single cannon: 58000 ft (17.678 km) ISA. Figure 6 represents the forces for 1:6 scaled F104 at the 1.6 M. The idea is to put two cannons at the wing tips. This solution has been successfully tested in the WWII Mustang F-51D. In our case, it is possible, at least structurally, to weld a titanium alloy insert to the cannon barrel and to laminate the composite wing on it. The cannon barrel is already made with titanium alloy. The design of the insert is critical due to the different coefficient of thermal expansion of the titanium alloy and the Carbon Fiber Reinforced Plastic (CFRP). Problems may arise due to the very thin and flexible UAVI wing with a huge mass on the tips. The overall drag of the system has an increase of about 10% in subsonic flight. Supersonic

Figure 5. 1:6 scaled F104 - Double cannon design (schematic).

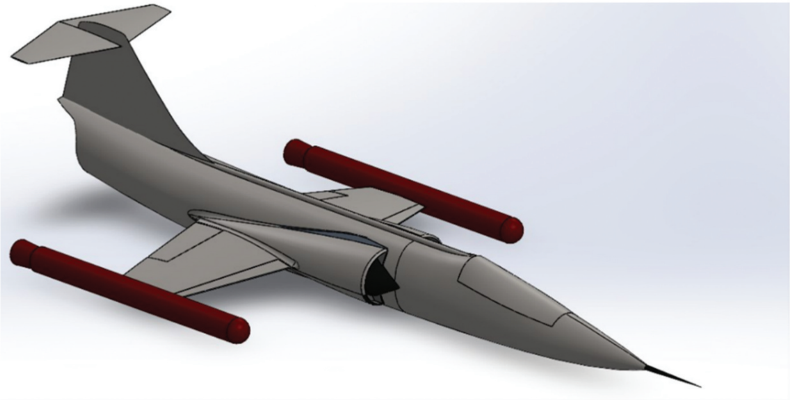
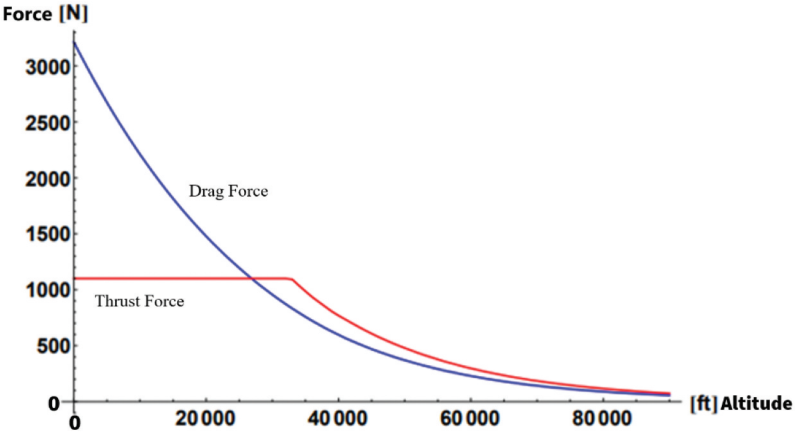


Figure 6. Force – altitude graph of 1:6 scaled F104 -single cannon design at 1.6 M.



flight is not possible anymore. Collapsible tails should be applied to the cannon nozzles. In this case, the CG is more correct and the UAVI should have improved pitch stability. This configuration will solve the reliability problem of s solve the reliability problem of single cannon-shot failure.

Information about F104 with different design versions is given in Table 3. This table has been created for the comparison between these different kinds of designs.

No true aerodynamic advantage on drag exists. The very long cannons give additional drag that is not compensated for by the "winglet" effect. The weight of the cannon in the wingtips, way outboard, reduces aileron response. Roll and yaw disturbances are amplified by inertia. The considerable form drag increases the drag coefficient of the whole UAVI or by about 10%. The wing loading increased by 25% at 65,000 m. The single cannon version with longer fuselage is still a better choice.

2.7. Fourth design iteration: the Blended Wide Body (BWB) balloon killer

The results of the previous concepts are that the UAVI should be highly subsonic to have enough thrust and should have the lower wing loading possible. Low drag at velocity between 0.8 M and 0.9 M is required. The airplane should have enough internal volume for the fuel and at least part of the payload. Two cannons (Figure 5) are preferred for reliability, while a single engine is preferred for controllability. A configuration like the Boeing B52 or a B787 configuration may be ideal. However, the literature contains a variety of concepts, such as conventional Tube and Wing (TAW), Flying Wing (FW), BWB, Integrated Wing-Body (IWB), and Hybrid Wing Body (HWB) (Ba Zuhair, 2019; Diamantidou et al., 2022; Ettoumi et al., 2023; XIE et al., 2021). According to Cayley's design principles, the necessary function for TAW is almost individually corresponding to the form.

For the concept of a flying wing, the wing performs all functions and is innately coupled. High aerodynamic efficiency is in opposition to stability and control, for example. In BWB, a single body with an extended chord length was used to provide volume, lift, hosts for the stabilizer/control surfaces, landing gear, embedded engines, and further to reduce wetted area to alleviate these conflicts and design challenges of FW. To further reduce the interferences and the resulting drag, a smooth transition between the body and wing is used. With no vertical or horizontal stabilizers and a multifunctional body, the BWB concept is created by combining all these features (Figure 7). When compared to FW, BWB has a larger centre body, an outer wing that is highly aerodynamically efficient

Table 3. Parameters of F104G (*) with a different design solution as a full-scale reference airplane

Parameter	F104G	F104 1:6 Single Cannon	F104 1:6 Dual Cannon
Length (m)	16.66	2.78	2.78
Wingspan (m)	6.63	1.1	1.3
Wing Area WA (m2)	18.22	0.5	0.5
MTOW (kg)	13166	20.75	30.5
Half Internal Fuel Mass (kg)	1138	8	8
Reference mass (kg)	12127	28.75	38.5
Dynamic Factor (DF)	1	0.68	0.68
Dynamic similitude	-	100%	133% (**)
Maximum static thrust T [N]	-	1100	1100
Maximum speed [M]	2	1.6 (***)	0.9

(*) Data of F104G from (Perinovic, 2022)

(**) this means that the model is heavier for Inertia (roll) of 33%

(***) limited by the fixed geometry air intake.

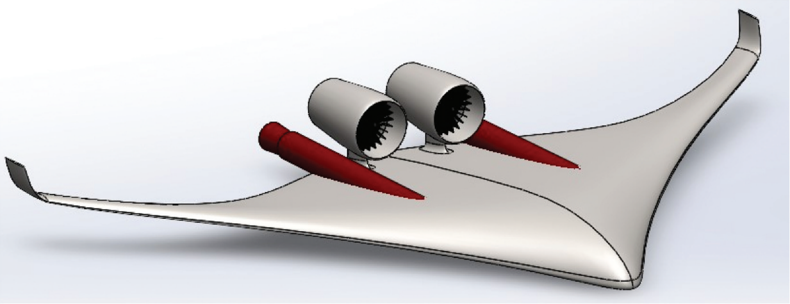


Figure 7. Blended wing body (BWB) UAVI design with two cannons (schematic).

and contributes to lift, and an area in the middle that is smoothly blended (integrated). Typically, the centre body's length is shorter than the span's width. Unlike in a traditional TAW configuration, there is no separate horizontal and vertical stabilizer. The outer wing, the highly swept angle of the outer wing, the rear centre body downloading, or any combination of these is always used to achieve longitudinal stability. The vertical winglets provide directional stability.

Elevons are a group of control surfaces that run from the centre body's trailing edge to the outer wing and serve as both an elevator and an aileron for longitudinal and lateral controls. The outboard splitting drag rudders and the rudders on the winglets work together to help control direction. The moment/lever arms for pitch and directional control are much shorter than those of a conventional TAW configuration. This fact is due to the positions of these control surfaces. Therefore, the areas of the elevons are large to satisfy the control authority's requirements, which results in lift loss and high hinge moments when additional longitudinal trim and stability augments are needed. A wetted-area reduction and a preferred spanwise lift distribution can be used to achieve high aerodynamic efficiency and a preferred structural weight of the wing. To overcome engine design challenges requirements, podded engines mounted on the rear centre body and additional vertical stabilizers are commonly used. Short moment arms have drawbacks, and to address them, the centre body is lengthened. BWB's centre body serves multiple purposes. When a spanwise elliptical lifting distribution is assumed, the centre body provides about 30% lift at cruise. Many more challenges are introduced by its integrations with engines and stabilizer/control surfaces.

Liebeck used the area of the trapezoidal wing as a reference area during the earlier development of BWB, but the definition of MAC is unclear. Gross planform area and the corresponding MAC serve as the standard reference values during development. The lift-to-drag ratio is unaffected by the specific reference values, but they do have an impact on the size of the force and moment coefficients and the ensuing stability margins. As a result, they are crucial for the design of flight control systems. The main advantages of BWB are skin friction drag is reduced because of less wet skin. By using relaxed stability in pitch, trim drag during cruise can be avoided. Reduced interference drags through a fluid centre body to wing transition. Improved spanwise lift distribution and reduced lift-induced drag brought on by lifting bodies. Reduction in wave drag at high transonic speed due to improved area-ruled shape. Due to reduced wing loading, simpler high-lift devices, lighter wings, and better high-altitude buffet margin can be achieved. Local inertia loading can reduce bending and shear loads on the structure by relieving local aerodynamic loading. Figure 7 shows a UAVI based on a BWB design. To compensate for the weight of the two shots locked in the rear of the cannon, the single engine was moved aft. The wing leading edge in front of the cannons is collapsible. This position also has the advantage of maximizing engine efficiency. The air intake of the BWB has the efficiency shown in Figure 8. The drag coefficient of the nacelle in function of engine frontal area is shown in Figure 9. The drag and trust curves with altitude at 0.85 M are shown in Figure 10. Cl and Cd curve at 0.85 M are shown in Figure 11. Also, all data for the UAVI BWB—twin cannon are given in Table 4.

Figure 8. Intake pressure recovery [%]- η_{intake} vehicle speed graph of BWB.

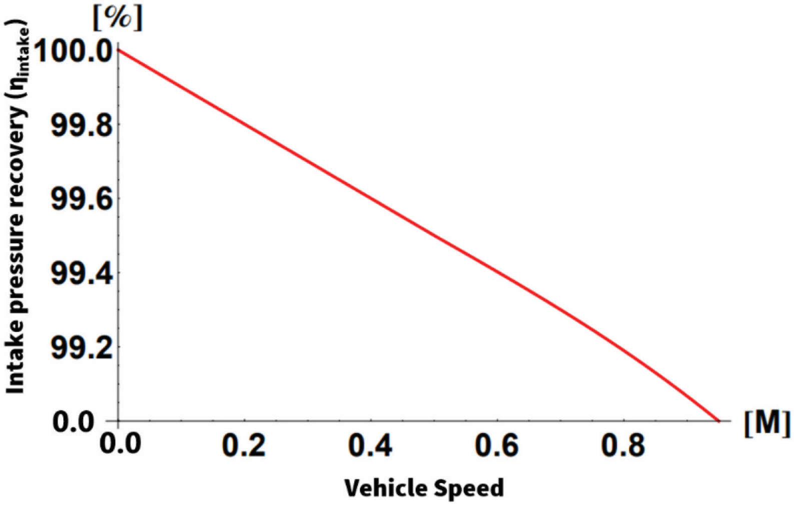


Figure 9. Drag coefficient (Cd) - vehicle speed (M) graph of engine nacelle of BWB.

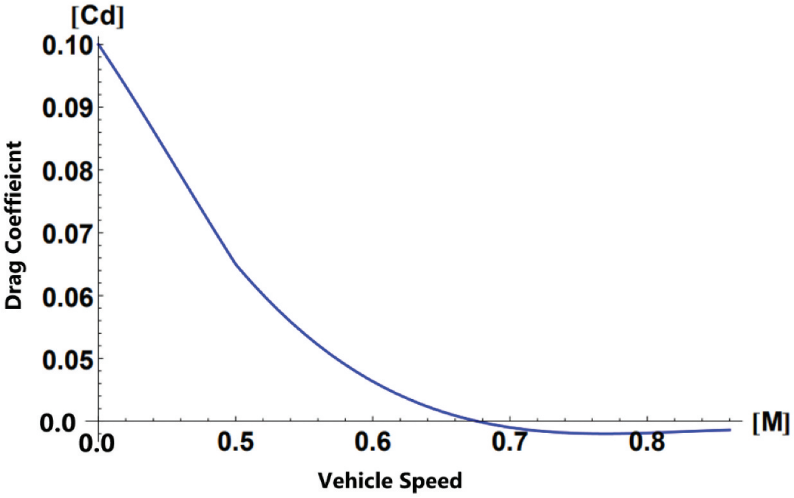


Figure 10. Force – altitude graph of BWB at 0.85 M.

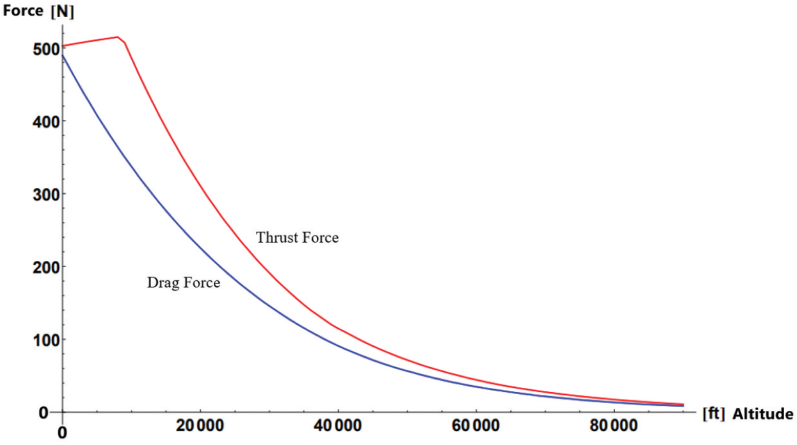


Figure 11. Drag coefficient (Cd) - lift coefficient (Cl) graph of BWB at 0.85 M.

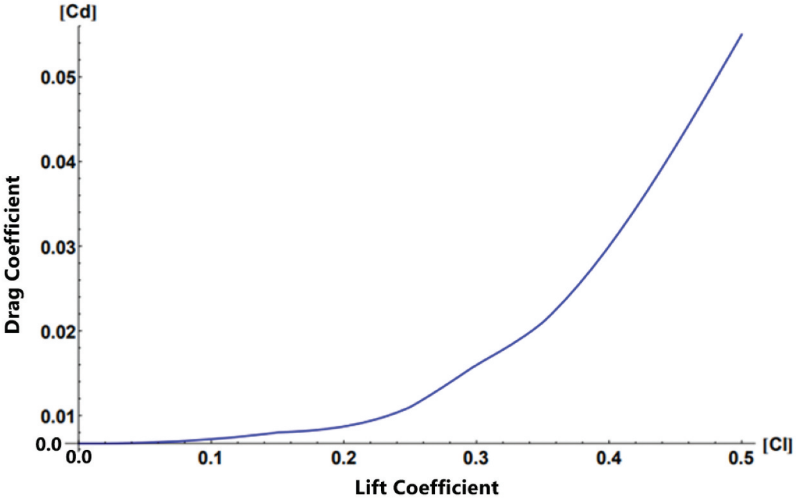
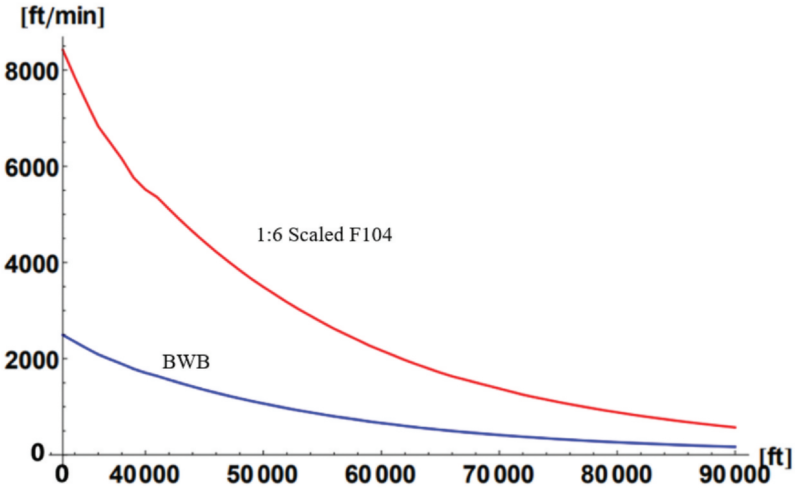


Table 4. Parameters of UAVI BWB twin cannon	
Parameter	**BWB**
Length (m)	1.42
Wingspan (m)	2.54
Wing Area WA (m2)	1.27
Maximum Take-off Weight MTOW (kg)	20.75
Half Internal Fuel Mass (kg)	8
Reference mass (kg)	50.7
Maximum static thrust T [N]	2 x 275=550

Figure 10 the nacelle drag (Figure 9) is subtracted to the microjet thrust (in the first chapter of this study Part I: weapons and mission). A comparison of the ROC of the BWB and F104 1:6 single cannon is shown in Figure 12. The F104 is obviously better performing with the possibility of zoom climbing at the last leg of the climb. In this way, the airplane slows down to a speed where shooting and collision avoidance manoeuvres are easier. The cannon needs to shoot at the static balloon within 500 meters. Most likely, it is more advantageous to dive immediately after firing at maximum range and attack the balloon from below at the conclusion of the zoom climb.

Figure 12. Rate of climb [ft/min]– altitude graph [ft] (1:6 scaled F104 at 1.6 M (red), BWB at 0.85 M (blue)).



2.8. Comparison between the UAVIs

The 1:6 scaled F104 has the advantage of a more acceptable wing loading due to the scaling down of the design. The CFD simulations showed that it is still acceptable to use the Cd and Cl of the full-scale airplane. The jet engine has, in a few conditions, a thrust that is not aligned to the one of the F104C that is the best performing version of the F104. In most cases, however, the scaled-down micro-jet engine has an acceptable thrust. After a nearly vertical climb at subsonic speed the 1:6 scaled F104 up to 40,000 ft (12.192 km) a shallow dive to 37,000 ft (11.277 km) makes it possible to reach the final speed of 1.6 M. This strategy is convenient because the F104 does not follow the "area-rule". The microjet should be used at full throttle to achieve the best efficiency. After the dive, the climb will take place at 1.6 M up to a maximum altitude of 95,000 ft (28.956 km). Over 65,000 ft (19.812 km) the manoeuvrability will degrade, but it will be better than the original F104C due to the lower wing loading. The 1:6 scaled F104–2-cannons will have roll control issues, overweight problems, and excessive drag. The 1:4 scaled F104 cannon will have too-low wing loading with problems in crosswind conditions and a maximum speed reduced to 0.9 M that will reduce the available thrust at high altitude. The 1:6 scaled F16 will have too low wing loading with problems in crosswind condition and a maximum speed reduced to 0.9 M that will reduce the available thrust at high altitude. The BWB would has the best performance except for the probability to fulfil the mission (reliability) due the two engines configuration. The uncertainty of a new design does not advice to adopt this solution. Comparison of the parameters between these UAVIs has shown in Table 5.

3. Results

The initial design of the balloon killing UAVIs is not simple. It has been determined that the best weapon system is a tiny 84 mm recoilless cannon that is loaded with airburst ammunition. The main problem arises because the powerplant requires velocity to recover pressure when operating at altitude. Recently, a balloon was launched at a height of 65,000 ft (19.812 km), and it may reach 90,000 ft (27.432 km). Their ability to use an autopilot and a guidance system is compromised at higher altitudes. Commercial microjets lack an afterburner and operate best at full load for TSFC. For economical reliability reasons, small UAVs with wingspan less than 3 m and MTOW less than 100 kg cannot use a variable geometry intake duct and nozzle. As a result, the system is optimized for nominal speed and altitude. With a properly constructed air intake, this UAVI can fly at supersonic speeds above 37,000 ft (11.277 km). It might easily reach 1.6 M. As a result, in

Table 5. UAVI comparison

Parameters	1:6 Scaled F104	1:4 Scaled F104	1:6 Scaled F104–2 cannons	1:6 Scaled F16	BWB
Manoeuvrability up to 65000ft (19.812 km)	Good	Acceptable	Acceptable	Good	Good
Manoeuvrability 65000ft −95000ft (19.812 km-28.956 km)	Acceptable	Acceptable	Bad (roll problems)	Bad	Good
Max speed	1.6M	0.9M	0.9M	0.9M	0.85M
MTOW	45kg	65kg	65kg	52.46kg	40.75kg
Number of cannons	1	1	2	1	2
Number of engines	1	1	1	1	2
Commercial RC model availability	yes	yes	no	yes	no
Cost	75,000USD	80,000USD	100,000USD	76000USD	120,000USD

an ideal mission, it will fly at this speed during the high-altitude portion of the flight, where pressure recovery and jet engine efficiency are at their highest. The cannon should fire when it is closer to the target than 500 m. At a distance around 1,000 m, the laser rangefinder should measure the distance of the balloon, and the ballistic computer should input the information into the airburst round. The UAVI will travel 1,000 m in 0.2 s if the cannon fires at 1.6 M. Therefore, the UAVI would have 0.1 s to avoid colliding with the balloon. Additionally, the shell's flight time will be extremely brief, necessitating likely a redesign of the ammunition. The airburst round will also be extremely fast, making it difficult to apply the right pressure and fragment pattern to the target. As a result, the UAVI needs to slow down during the final portion of the flight. Due to this, the F104–1:6 UAVI may zoom climb to slow down, converting speed to altitude, and engaging the balloon at subsonic speed. The takedown procedure would be simpler and more effective in this way. However, a mistake in the flight and fire process would render the attack ineffective. Additionally, at such altitudes, the UAVI cannot be throttled. It would be necessary to dive to recover 1.6 M once the speed is decreased. It is then possible to repeat the process. In any case, the second attack will be possible only if the single round had not been already fired. The balloon's extremely slow speed and the fact that the HE round's ignition timing is not crucial are advantages. In fact, if the round detonates before, on, or after the balloon-sealed structure, the balloon would also be destroyed. The BWB's mission is much easier. In this case, the engagement is simpler because the UAVI is already moving at a high subsonic speed. The BWB UAVI, however, has a few drawbacks. Theoretically, the 1:6 scaled F104's propulsion system is less dependable. In fact, the mission's success would be hampered by a single-engine failure. However, with only one engine operative, the BWB UAVI cannot fly at altitudes. Due to its larger size, two engines, and two cannons, the BWB is more expensive. A BWB UAVI could very well cost more than twice as much as a 1:6 F104. The third part of this paper will address reliability and cooling issues.

4. Discussion

It appears that there are currently two different weapon systems that can bring down a high-altitude balloon. Utilizing a fighter and a missile is the first option. Due to the high price of the fighter and missiles, this alternative is very costly. The use of HALE/HAP (High Altitude Long Endurance/High Altitude Platform) UAVs outfitted with lasers appears to be another alternative. There are several issues with this alternative. The main one is that designing a HALE/HAP for such altitudes is difficult. The requirement for refueling cannot put a limit on the endurance. Extremely long-range solar-powered fixed-wing aircraft must therefore generate the energy needed during the day and recharge batteries for the evening. Fuel cells are an alternative that can be used to store electricity at night and hydrogen during the day. The HALE/HAP UAV will avoid turbulence at a height of 65,000 ft (19.812 km) in winds of less than 5 kn. Furthermore, the FAA's mandated Class-A airspace ends at 60,000 ft (18.288 km), and the maximum altitude for commercial flights is 56,000 ft (17.069 km). The design of HALE/HAP is incredibly challenging for several reasons. The first is that the use of extremely large wings that must be very light is required due to the relatively low speed (300 kn) and the extremely thin air. As a result, flutter and stiffness issues on the climb and descent are frequent at lower altitudes. The HALE/HAP UAV has very little controllability during take-off and landing and is highly sensitive to crosswind. The coffin corner, or the difference between stall and cruise speed at altitude, is another issue. The need for large propeller disks and cooling down the electric motors, among other issues, make the multiengine/multi-propeller solution necessary. Additionally, solar panels' efficiency and lifetime are decreased by severe cooling issues caused by temperatures that may consistently stay around 60 DEG C. Due to Lusser's law and the numerous components, the reliability figure is crucial. Even a relatively low-power laser installation complicates the already extremely complex design. Installing a powerful laser on a commercial airliner or a modified bomber is a more practical solution. Both the satellite blinding and balloon downing versions of this solution have already been tested and found to work. Additionally, this solution is very pricy. Utilizing small UAVI appears to be a much more cost-effective solution. As a result of the wide range of commercial parts available from the small satellite market to the most affordable RC models, the design of a dependable, economical, and compact UAVI is relatively straightforward. The ability to produce thousands of UAVIs per day significantly lowers costs. Since inexperienced operators could launch thousands of UAVI from ramps, this is a possibility. There could be one or more cannons on this UAVI. Their ability to harm targets is constrained by the single round per cannon. However, quantity boosts the UAVI's effectiveness. Even though the idea is not original, these papers (Parts 1 and 2) show that it is still viable. The range of about 300 km and the brief flight time are the main restrictions because of the real-time communication capabilities and the low efficiency of microjets. Table 6 provides a summary of the costs. The ground station with the launching unit and the rescue station must be added. The UAVI is clearly more affordable than an AIM9 Sidewinder, which costs more than 400,000 USD each.

The downsized F104C 1:6 single cannon seems to be the best choice. As in many cases, the smaller, fastest airplane is best one. The original wing loading of the F106C at 58,000 ft (17.678 km) is reached in the downsized model only at 65,000 ft (19.812 km) (1–3). Below this altitude the UAVI will have better manoeuvrability. This fact limits its capability to fly in turbulence. For this reason, it is necessary to keep the UAVI at high speed. The original RC model is already manufactured with CFRP (Carbon Fiber Reinforced Plastic). It is convenient to use top-performance CFRP for the UAVI. The small size and the improved material performance will compensate the larger stresses due to higher speed (1.6 M) and higher g loading (25 g). The speed is limited by the fixed geometry air intake optimized for high altitude. Variable geometry nozzles are available also for the RC models. The g limit is due to the turbojet bearings load capacity. In this pure turbojet the maximum efficiency is reached at maximum throttle, a condition that can be kept for the climb phase. The high fuel consumption is compensated by the short flight time. If necessary, it is possible to increase the fuel capacity by adding a fuselage section in front of the wings. This operation is aerodynamically sound as demonstrated by the CFD simulations that proved that the full size drag and lift coefficients can be used also in the 1:6 UAVI at least in the preliminary phase. The forward displacement of the GC due to the longer fuselage restores the longitudinal stability that is compromised by the cannon in the tail. Additional cooling is necessary for the electronics. A Peltier system can be used to transfer the heat in the fuel tank. The fuel tank is pressurized by air spilled from the compressor. This solution is common in RC models. More details are given in the third part of this paper that deals with reliability and availability. The C version of the F104 was chosen due to the best overall performance of this version, that was also the altitude record breaker.

Table 6. Bill of materials of the 1:6 F104C single cannon

Item	USD
Carbon Fiber Reinforced Polymer CFRP Structure	2,000
Engine assembly	20,000
Servos and controller	2,000
Automatic Pilot	1,000
Radio	3,000
Sensors	3,000
Auxiliary cooling systems	1,000
Cannon with computer and rangefinders	25,000
Single shell cost	5,000
Fuel system	1,000
SAR radar	2,000
Extras	7,000
Assembly	3,000
TOTAL	75,000

5. Conclusions

The second part of this paper demonstrates how small UAVIs for balloon takedown can be easily designed using components that are available for purchase in stores. The most profitable commercial RC-model derivative was a modified 1:6-F104 jet that won comparison testing with several other models. For this model, new wings and air intakes must be added, along with a longer fuselage and a cannon. The original microjet engine should be replaced with the largest one currently on the market. The 1:6 F104 can shoot down balloons up to 95,000 ft (27.4 km) thanks to its 84 mm cannon. The mission needs to be well thought out, though, in order to succeed. A 2-cannons-BWB subsonic UAVI made specifically for design altitude is an alternative. However, it seems that in terms of cost-effectiveness, the modified RC 1:6 scaled F104 model performs better than the BWB design. Finally, these small UAVIs (MTOW below 100 kg, wingspan below 3 m, cost below 100,000USD) appear to be effective for many other applications due to the possibility of mass production and extremely high-cost effectiveness. The “missile with wing” F104 design finds in the downscale version a lower wing loading that perfectly suites the highest altitude that can be reached by the UAVI without zoom climbing. The UAVI lower wing loading will improve the handling and climbing performance of the F104 at lower altitudes. The similitude criteria showed that up to 65,000 m the UAVI will perform better than the full-scale “missile with wing” airplane. At higher altitude Manoeuvrability will be reduced but will be acceptable up to the required 95,000 ft (27.4 km). The 1:6 scaled F104 will be able to maneuver and attack the balloons and will use the huge 84 mm cannon with the airburst round. The SAR radar and the rangefinder will give the possibility to input into the shell the right time-to-burst. The HE airburst shell will defeat any balloon envelope by tearing and piercing. Single mission costs will be higher than the required 3,000 USD. In fact, the airburst round costs 5,000 USD. The part III of this paper shows that the UAVI will last 10 missions (TBO) in order to have the necessary reliability. In addition, several UAVIs are necessary to cover the territory. In fact, the maximum range of the UAVI is “only” 320 km due to real-time communications requirement. The UAVI will not have large weather limitations due to the high speed (up to 1.6 M) and the possibility to install commercial, available, industrial-grade deicing systems on wings, air intakes and probes. The high speed will reduce crosswind and turbulence problems. The high thrust will allow you to take-off from ski level with a 4 m takeoff run and a ski jump. In alternative a catapult can be used. The UAVI will not have a landing gear and will use a jettisonable tricycle gear-style trolley to take off. A wire-hook system will assure the rescue after the mission. The use of a two engine UAVI is not advisable due to the reduced reliability. In fact, the UAVI cannon fulfill the mission with one engine operative. Also, the availability would be reduced, and the cost would be higher. The concept seems promising and susceptible of further study.

6. Future work

Due to the new UAVI’s extensive use of commercially available parts that were not intended for high-altitude weapon systems, reliability is a crucial issue. It’s important to take care of the high-altitude cooling issues as well. Even though the F104C set a record for the highest altitude reached with zoom climbing at 103,395 ft (31.515 km), the aerial vehicle’s overall Manoeuvrability is equally important. It was demonstrated through CFD simulations on the original F104C and the smaller UAVI that the F104 Flight Manual could be used for the initial design. Further research is required for the evaluation, though, due to the new air intake and the inevitable differences.

Funding
This research received no external funding.

Author details
Luca Piancastelli[1]
Christian Leon-Cardenas[1]
E-mail: christian.leon2@unibo.it
ORCID ID: http://orcid.org/0000-0002-6430-4615
Eugenio Pezzuti[2]
Merve Sali[1]

[1] Department of Industrial Engineering, Alma Mater Studiorum Università di Bologna, Bologna, Italy.
[2] Dipartimento di Ingegneria dell’Impresa “Mario Lucertini”, Università di Roma “Tor Vergata”, Via del Politecnico, Roma, Italy.

Author contributions
Conceptualization, L.P., C.L. and M.S.; methodology, L.P., C. L. and M.S.; software, L.P.; validation, C.L. and M.S.; formal analysis, L.P., C.L. and M.S.; investigation, L.P., C.L. and M.

S.; resources, L.P.; data curation, C.L. and M.S.; writing—original draft preparation, C.L. and M.S.; writing—review and editing, M.S., C.L.; visualization, C.L.; supervision, L.P.; project administration, L.P.; funding acquisition, L.P.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Citation information

Cite this article as: Cost effectiveness and feasibility considerations on the design of mini-UAVs for balloon take-down. Part 2: Aircraft design approach selection, Luca Piancastelli, Christian Leon-Cardenas, Eugenio Pezzuti & Merve Sali, *Cogent Engineering* (2023), 10: 2257958.

References

Ahmed, M. Y. M., & Qin, N. (2020). Forebody shock control devices for drag and aero-heating reduction: A comprehensive survey with a practical perspective. *Progress in Aerospace Sciences*, *112*, 100585. https://doi.org/10.1016/j.paerosci.2019.100585

Alam, M. I., Pasha, A. A., Jameel, A. G. A., & Ahmed, U. (2023). High altitude airship: A review of thermal analyses and design approaches. *Archives of Computational Methods in Engineering*, *30*(3), 2289–2339. https://doi.org/10.1007/s11831-022-09867-9

Ba Zuhair, M. A. (2019). Trailing edge geometry effect on the aerodynamics of low-speed BWB aerial vehicles. *Advances in Aircraft and Spacecraft Science*, *6*(4), 283–296. https://doi.org/10.12989/aas.2019.6.4.283

Bian, J., Wang, X., & Gao, S. (2021). Experimental aeromagnetic survey using a rotary-wing aircraft system: A case study in Heizhugou, Sichuan, China. *Journal of Applied Geophysics*, *184*, 104245. https://doi.org/10.1016/j.jappgeo.2020.104245

Col Mandeep Singh. (2022). *Contested Air Littoral and the Challenges Ahead*. Indian Defence Review. http://www.indiandefencereview.com/news/contested-air-littoral-and-the-challenges-ahead/

Cunningham, K., Foster, J., Murch, A., & Morelli, E. (2008). Practical application of a Subscale Transport aircraft for flight Research in control upset and failure conditions .*AIAA Atmospheric Flight Mechanics Conference and Exhibit*, 6200. https://doi.org/10.2514/6.2008-6200

Dai, Q., Fang, X., Li, X., & Tian, L. (2012). Performance simulation of high altitude scientific balloons. *Advances in Space Research*, *49*(6), 1045–1052. https://doi.org/10.1016/j.asr.2011.12.026

Dantsker, O. D., Haviland, S. T., Allford, R., Daley, D., Danowsky, B. P., Haplin, D., Kendall, G., Lisoski, D. L., Liu, Z. T., Mukherjee, J., Peltz, A., Price, B., Sano, G., Warner, R. B., & Bershadsky, D. (2023). Flight testing of tailless subscale HAPS aircraft. In *AIAA AVIATION 2023 forum*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2023-3780

Das, N., Pandey, K. M., & Sharma, K. K. (2020). A brief review on the recent advancement in the field of jet engine - scramjet engine. *Materials Today: Proceedings*, *45*, 6857–6863. https://doi.org/10.1016/j.matpr.2020.12.1035

Diamantidou, D. E., Hosain, M. L., & Kyprianidis, K. G. (2022). Recent Advances in boundary Layer ingestion Technology of evolving powertrain systems. *Sustainability (Switzerland)*, *14*(3), 1731. https://doi.org/10.3390/su14031731

Ettoumi, S., Zhang, Y., Cui, B., & Zhou, J. (2023). Failure Initiation analysis of a PRSEUS BWB wing subjected to structural damage. *Aerospace*, *10*(4), 341. https://doi.org/10.3390/aerospace10040341

Fox, M. C. (1993). *Supersonic aerodynamic characteristics of an advanced F-16 derivative aircraft configuration* (Vol. 3355). NASA.

Gökbel, E., & Ersoy, S. (2021). Launchable rotary wing UAV designs and launch mechanism designs for rotary wing UAV. *Journal of Mechatronics and Artificial Intelligence in Engineering*, *2*(2), 102–113. https://doi.org/10.21595/jmai.2021.22339

Grieco, K. A. B. M. K. (2018). *Weaponized balloons challenge US air superiority*. DefenseNews. https://www.defensenews.com/opinion/commentary/2023/03/07/weaponized-balloons-challenge-us-air-superiority-quite-littorally/

Hasan, I., Mukesh, R., Babu, D., Ramakrishnan, S., & Ponnusamy, R. (2022). Forward flight performance analysis of supercritical airfoil in helicopter main rotor. *Intelligent Automation & Soft Computing*, *33*(1), 567–584. https://doi.org/10.32604/iasc.2022.023252

He, S., Guo, S., Liu, Y., & Luo, W. (2021). Passive gust alleviation of a flying-wing aircraft by analysis and wind-tunnel test of a scaled model in dynamic similarity. *Aerospace Science and Technology*, *113*, 106689. https://doi.org/10.1016/j.ast.2021.106689

Ibrahim, B., & Noura, H. (2020). Formation flight control of multi-uav system using neighbor-based trajectory generation topology. *WSEAS Transactions on Applied and Theoretical Mechanics*, *15*, 173–181. https://doi.org/10.37394/232011.2020.15.20

Leventopoulos, S. A. (2019). Ground based air defense systems new challenges and prospective. *Journal of Computations & Modelling*, *9*(2), 1792–8850. https://www.scienpress.com/Upload/JCM/Vol%209_2_5.pdf

Liu, Y., Wang, H., & Fan, J. (2019). Novel docking controller for autonomous aerial refueling with probe direct control and learning-based preview method. *Aerospace Science and Technology*, *94*, 105403. https://doi.org/10.1016/j.ast.2019.105403

LTC Gregory P. Shipper. (2020). *The Battle of Britain: The First Integrated Air Defense System*. https://apps.dtic.mil/sti/pdfs/AD1159878.pdf

Maurer, K. (2021). Flattened vision: Nineteenth-century hot air balloons as early drones. In Graae, M., & Andreas, K. (Eds.), *Drone imaginaries* (pp. 19–38). Manchester University Press.

Murch, A. (2008). A flight control System architecture for the NASA AirSTAR flight test infrastructure. In *AIAA Guidance, Navigation and Control Conference and Exhibit*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2008-6990

Noël, J., Renson, L., Kerschen, G., Peeters, B., Manzato, S., & Debille, J. (2013). *Nonlinear dynamic analysis of an F-16 aircraft using GVT data*. IFASD 2013 - International Forum on Aeroelasticity and Structural Dynamics.

Perinovic, E. J. (2022). *Ex machina: The Lockheed F-104G Starfighter, the Federal Republic of Germany, and the European military Aviation sector 1955–1975*. Temple University.

Pope, A. P., Ide, J. S., Mićović, D., Diaz, H., Rosenbluth, D., Ritholtz, L., Twedt, J. C., Walker, T. T., Alcedo, K., & Javorsek, D. (2021). Hierarchical reinforcement learning for air-to-air combat. *Proceedings of the 2021 International Conference on Unmanned Aircraft Systems (ICUAS)*, Athens (pp. 275–284).

Raju Kulkarni, A., La Rocca, G., Veldhuis, L. L. M., & Eitelberg, G. (2022). Sub-scale flight test model design: Developments, challenges and opportunities. *Progress in Aerospace Sciences*, *130*, 100798. https://doi.org/10.1016/j.paerosci.2021.100798

Salari, M. E., Coleman, J., O’Donnell, C., & Toal, D. (2020). Experimental rig investigation of a direct interconnection technique for airborne wind energy systems.

International Journal of Electrical Power & Energy Systems, *123*, 106300. https://doi.org/10.1016/j.ijepes.2020.106300

Seshagiri, S., & Promtun, E. (2008). Sliding mode control of F-16 longitudinal dynamics. *Proceedings of the 2008 American Control Conference*, Seattle (pp. 1770–1775).

Shao, S., Jia, G., Yin, P., Hou, Z., Zhang, L., & Guo, Z. (2022). Trailing-edge jets for UCAV's flight control over a wide speed range. *Aerospace Science and Technology*, *128*, 107788. https://doi.org/10.1016/j.ast.2022.107788

Shen, T., & Ochiai, H. (2021). A UAV-Enabled wireless powered sensor network based on NOMA and cooperative relaying with altitude optimization. *IEEE Open Journal of the Communications Society*, *2*, 21–34. https://doi.org/10.1109/OJCOMS.2020.3042257

Tony Landis. (2021). *Flashback: Lockheed NF-104A Aerospace trainer*. Air Force Materiel Command History Office. https://www.wpafb.af.mil/News/Article-Display/Article/2854337/flashback-lockheed-nf-104a-aerospace-trainer/

Tumbarska, A. (2021). Non-lethal technologies for forced stopping potentially dangerous vehicles and vessels. *Security & Future*, *5*(2), 71–74. https://stumejournals.com/journals/confsec/2021/2/71

Weinberg, G. V. (2021). Quantification of combat team survivability with high power rf directed energy weapons. *Progress in Electromagnetics Research M*, *102*, 1–11. https://doi.org/10.2528/PIERM21020406

Wei, Z., Zhang, S., Jafari, S., & Nikolaidis, T. (2020). Gas turbine aero-engines real time on-board modelling: A review, research challenges, and exploring the future. *Progress in Aerospace Sciences*, *121*, 100693. https://doi.org/10.1016/j.paerosci.2020.100693

Xia, T., Dong, H., Yang, L., Liu, S., & Jin, Z. (2021). Investigation on flow structure and aerodynamic characteristics over an airfoil at low Reynolds number—A review. *AIP Advances*, *11*(5). https://doi.org/10.1063/5.0044717

XIE, Y., SAVVARISAL, A., TSOURDOS, A., ZHANG, D., & GU, J. (2021). Review of hybrid electric powered aircraft, its conceptual design and energy management methodologies. *Chinese Journal of Aeronautics*, *34*(4), 432–450. https://doi.org/10.1016/j.cja.2020.07.017