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# Relationship Between Wingspan and Fuselage Length in Aircraft According to Engine Types

**Seyhun Durmuş**[1*]

[1*]Balikesir University, Edremit School of Civil Aviation 10300, Edremit, Balikesir, Türkiye. (drmsyhn@gmail.com)

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Corresponding Author: *Seyhun Durmuş*

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## Abstract

The study aims to explain the size relationship between wingspan and fuselage length, which are the two basic design parameters that a designer is most curious about. Within the scope of the study, the relationship between take-off mass, fuselage length and wingspan of a total of 601 aircraft was questioned for single-piston, twin-piston, turboprop, and jet aircraft types. Power correlations were used for mass-based sizing of wingspan and fuselage length. In mass-based sizing, bad correlations were found for fuselage length for single-piston airplanes and good correlations for turboprops and jets. In terms of wingspan to fuselage length ratio ($b/l_{fus}$) jets showed a more pronounced trend, ranging from 0.7 to 1.1, while other aircraft types showed different trends, ranging from 0.9 to 1.7. In general, racer, homebuilt, aerobatic, and light transport aircraft have low $b/l_{fus}$ ratios, while motor gliders, firefighters, patrol, and agricultural aircraft have high $b/l_{fus}$ ratios. The study is valuable in that it fills a gap in the literature by considering the relationship between wingspan and fuselage length both with correlations over mass and by revealing statistics according to aircraft types over proportional relationship.

## 1. Introduction

Wingspan and fuselage length, which are related to the take-off mass of the aircraft, are the main dimensional parameters that affect the parking area occupied by the aircraft in the hangar or apron. ICAO categorized aircraft into 4 main groups based on maximum take-off mass, taking into account wake turbulence category: J (Super) type of aircraft (A380) with a maximum take-off mass of 560 000 kg, H (Heavy) type of 136 000 kg or more (except those specified as J); M (Medium) type of aircraft less than 136 000 kg and more than 7 000 kg; and L (Light) type of aircraft 7000 kg or less (ICAO, 2017). ICAO categorized the wingspan length of aircraft into 6 main groups with aerodrome reference code letters from A to F: A with a wingspan < 15 m, B with 15 m but < 24 m C with 24 m but < 36 m, D with 36 m but < 52 m, E with 52 m but < 65 m, F with 65 m but < 80 m (ICAO, 1988).

Torenbeek (2013) claimed that the ratio of fuselage length to diameter is the basic parameter affecting aircraft total drag with body frontal area and wetted area. Fuselage length of the aircraft is the sum of the nose cone, cabin, and tail cone lengths. Since the fuselage fineness ratio effect the aircraft total drag, the nose length and tail cone length are generally defined on fuselage diameter. The fuselage nose length to diameter ratio is between 1.2-2.5 and tail cone fuselage length to diameter ratio is about 2-5 (Sforza, 2014). Raymer (2018) proposed an approach to estimate fuselage lengths using take-off gross mass. Raymer presented on a power correlation data between the mass and fuselage length for different types of aircraft (sailplanes, homebuilt, general aviation, jets). Liu (2006) claimed that wingspan is proportional to the one-third-power of the weight. Nicolosi et al. (2016) used computational fluid dynamics to predict fuselage drag for regional turboprop aircraft. This study concluded that the fuselage coefficient and lateral rolling moment coefficients should be neglected, and future studies should focus on fuselage shape and wing-fuselage interferences. Anderson and Takahashi (2017) proposed computer aided design and finite element analysis for the structural design of fuselage. Singh et al. (2016) in conceptual design of transport aircraft, a genetic algorithm was used to optimize the fuselage length and wing aspect ratio. According to Wells et al. (2017) for conventional tube with wing designs, fuselage sizing is used to support aircraft weight estimation with the flight optimization system (FLOPS). A slender fuselage does not have a significant effect on the lift distribution in an upswept wing, whereas it produces a greater change in the lift distribution in swept wings (Zlotnic & Diederich, 1952).

There are also studies on original fuselage designs in the literature. The unsymmetrical fuselage models affect the pitching moment coefficient, so unsymmetrical cambered fuselage is difficult to implement (Abubakar et al, 2013). Bejan et al. (2014) found that large or small, aircraft show a proportionality between wingspan and fuselage length, and between fuel load and aircraft size. Also, Bejan et al. (2013) revealed correlations between aircraft mass, speed, engine mass, range. Ardema et al. (1996) developed a computer program (PDCYL) for analytical estimation of fuselage and wing weight for transport aircraft based on basic structural principles. Bronz (2012) proposed multiplying the wingspan by a coefficient of 0.8 for the estimate of fuselage length of mini-UAV. Kruger et al. (2016) argued that the low fineness ratio provides savings in structural weight as well as reduction in fuel consumption and total drag. Marta (2008) studied on a genetic algorithm for optimization of small regional jet geometry with parameters of fuselage length, fuselage diameter, wingspan, wing chord. Nita and Scholz (Nita & Scholz, 2010) investigated aircraft cabin parameters for optimum slenderness parameter namely fuselage length-to-fuselage diameter using chromosomal algorithm and basic methods. McDavid and Kuhner (2017) studied the effect of fuselage lengths on determination of the tail lever for different tail configurations. The study claimed that the landing angle reserve and length of landing gear legs were for increase of fuselage length (Zhuralev, 2012).

This study aims to fill the gap in the literature by considering the relationship between wingspan and fuselage length with mass-based power correlations and presenting statistics according to aircraft types.

## 2. Materials and Methods

In this study, take-off gross weight (kg), wingspan (m), and fuselage length (m) data of 601 aircraft were compiled from Jane's All the World's Aircraft (Jackson, 2004). Details by type of aircraft examined are as follows: 285 passenger jets, 163 single piston aircraft, 61 twin piston aircraft, and 92 turboprops.

$$l_{fus} = am_g{}^c \tag{1}$$

Raymer (2018) proposed an approach of estimating fuselage lengths with take-off mass as a method. In this study, Raymer's power correlation methodology was applied to data of 601 aircraft. This method is given in Eq. 1 where m is in kg and $l_{fus}$ is in meter. Similarly, wingspan (b) is calculated as given in Eq. 1.

## 3. Result and Discussion

In this study, the relationships of fuselage length and wingspan were revealed depending on the take-off mass parameter for single-piston, twin-piston, turboprop, and jet aircraft. Power correlation of fuselage lengths in terms of weight parameter according to 4 aircraft types is given in Fig. 1 on a base 10 logarithmic scale. In terms of fuselage length, the weakest correlations were found in single-piston aircraft, followed by twin-piston aircraft. As seen from the slopes of the curve, in unit weight; the highest fuselage lengths are in jet and turboprop aircraft, and the lowest fuselage lengths are in single pistons. The biggest difference in terms of fuselage length is between the light jets and passenger jets.

The aircraft designs with the lowest and highest values in terms of fuselage length among the examined aircraft, are listed below by aircraft types. In the study, the design data of both civil aircraft and military aircraft were also examined. In the single-piston aircraft examined: Acro Sport has a fuselage length of 5.3 m and that of the An-2 is 12.4 m. In twin-piston aircraft examined: 680 E commander has a fuselage length of 7.38 m and that of the CL-215 is 19.82 m. In the turboprop aircraft examined: King Air has a fuselage length of 10.82 m and that of the Dash 8 is 32.84 m. In jet aircraft examined: Cessna A-37 has a fuselage length of 8.62 m and that of the Boeing 747 is 76.25 m (Jackson, 2004).


**Figure 1.** Representation of power correlation between fuselage length and aircraft mass on a base 10 logarithmic scale for different engine types.

According to the statistics presented in Fig. 2, the relationships between wingspan and mass gave an overall high $R^2$ value, except for single-piston aircraft. As seen from Fig. 2, in terms of wingspan, the weakest correlations were found in single-piston aircraft. As can be seen from the slopes of the curve, in unit weight; jet have the lowest wingspan with other aircraft types showing similar trends.

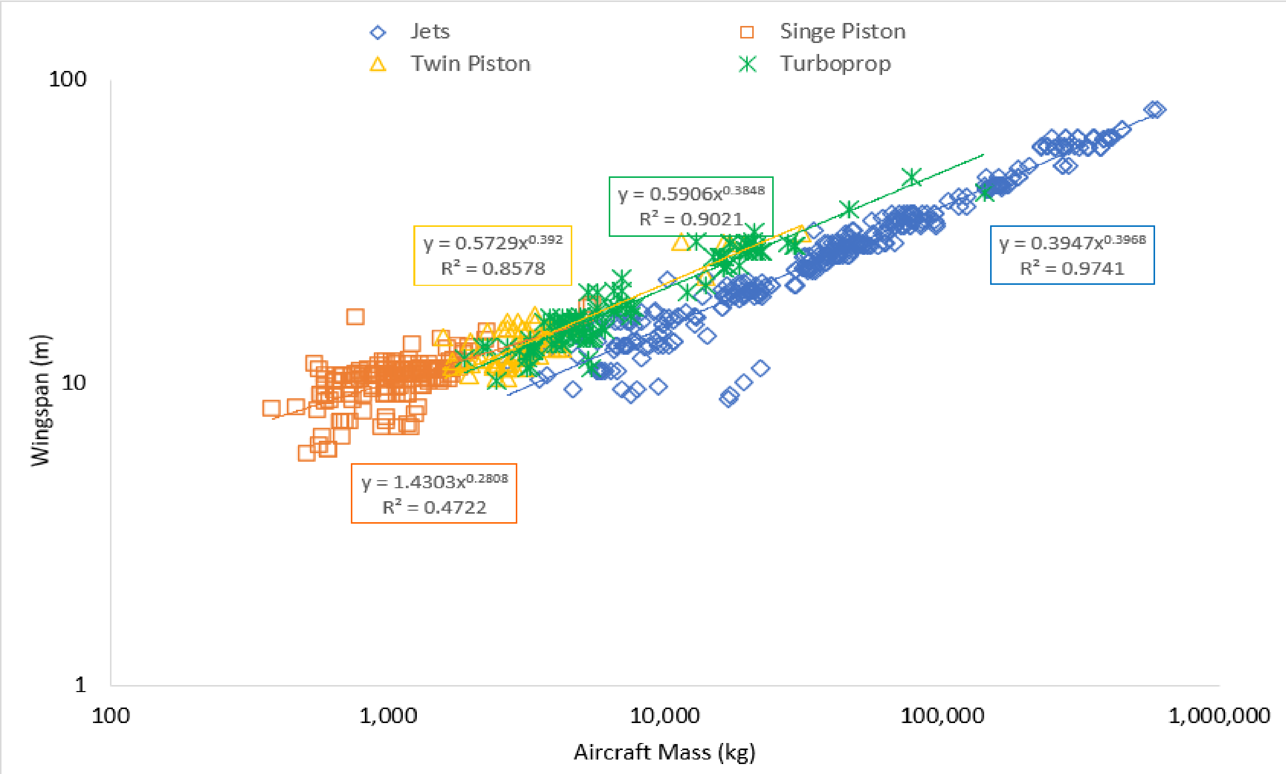



**Figure 2.** Representation of power correlation between wingspan and aircraft mass on a base 10 logarithmic scale for different engine types.

The coefficient values of power correlation obtained from the statistical data of the fuselage length change according to the weight parameter are shown in Table 1 together with $R^2$ values. In terms of both fuselage length and wingspan, the worst correlations were found in single-piston aircraft, while the best correlations were found in jets followed by turboprops. Good correlations found in jet and turboprop aircraft show that aircraft have a more uniformly distributed density (more homogeneous payload) along the fuselage than single-pistons.

**Table 1.** Power correlation between fuselage lengths and wingspan in terms of take-off mass

| **Fuselage Length Correlations** | | | | **Wingspan Correlations** | | | |
|---|---|---|---|---|---|---|---|
| $l_{fus} = a\ m_g^C$ | | | | $b = a\ m_g^C$ | | | |
| **Aircraft Type** | **a** | **c** | **$R^2$** | **Aircraft Type** | **a** | **c** | **$R^2$** |
| Single Pistons | 1.22 | 0.25 | 0.69 | Single Pistons | 0.14 | 0.28 | 0.41 |
| Twin Pistons | 0.64 | 0.35 | 0.80 | Twin Pistons | 0.57 | 0.39 | 0.78 |
| Turboprops | 0.27 | 0.45 | 0.90 | Turboprops | 0.59 | 0.38 | 0.90 |
| Jets | 0.39 | 0.41 | 0.95 | Jets | 0.39 | 0.39 | 0.94 |

One of the most curious issues of a designer who wants to size aircraft is how the relationship between wingspan and fuselage length varies according to types of aircraft. Fig. 3 shows the wingspan/fuselage length ($b/l_{fus}$) ratios of 601 aircraft. Wingspan/fuselage length ($b/l_{fus}$) ratios are concentrated in different ranges for certain aircraft types. The $b/l_{fus}$ range (min.-max.) is 1.04-2.25 for single piston aircraft, 0.88-2.14 for twin-piston aircraft, 0.86-1.82 for turboprop aircraft and 0.61-1.27 for jets. Considering the mean $b/l_{fus}$ values, single piston aircraft have highest $b/l_{fus}$ ratio and jets have lowest $b/l_{fus}$ ratio.

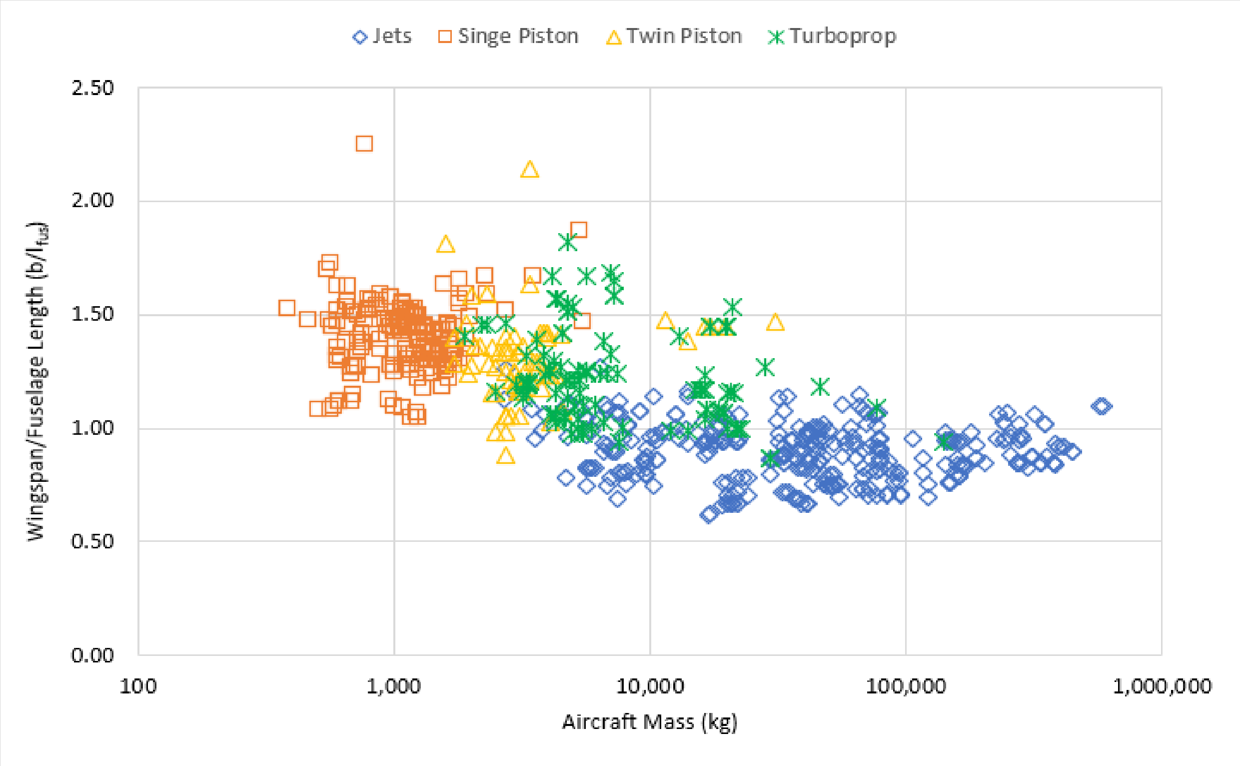
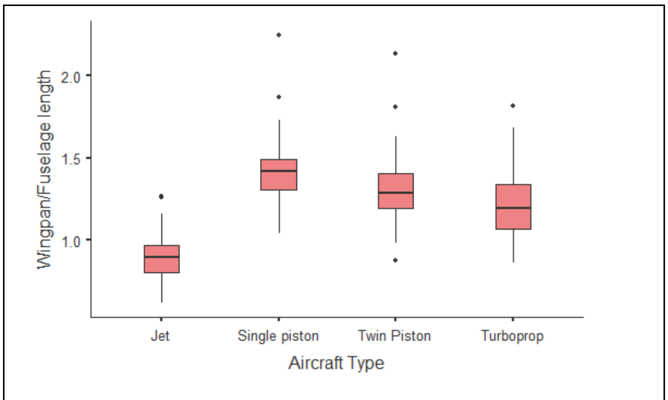



**Figure 3.** Display of the ratio of wingspan to fuselage length for different type of aircraft

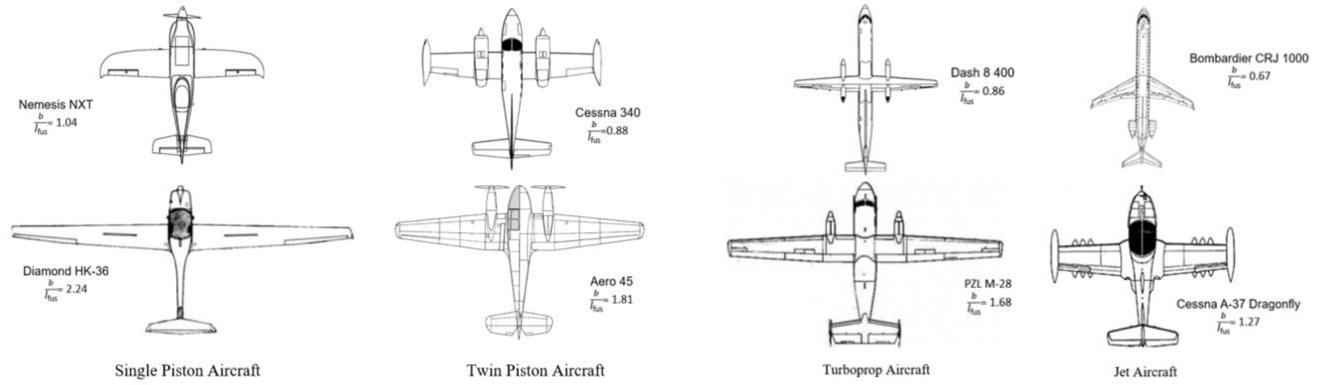



| Aircraft Type | N | Mean Wingspan/Fuselage Length | SD |
|---|---|---|---|
| Jet | 285 | 0.896 | 0.125 |
| Single piston | 163 | 1.400 | 0.158 |
| Twin Piston | 61 | 1.303 | 0.196 |
| Turboprop | 92 | 1.217 | 0.197 |

**Figure 4.** Boxplot display of $b/l_{fus}$ frequency distribution with mean and standard deviation values

Fig. 4 shows wingspan/fuselage length ($b/l_{fus}$) frequency distributions in a boxplot with basic statistics. In terms of wingspan to fuselage length ratio, singe piston props, twin piston, and turboprop aircraft showed similar trends, while jets showed a distinct trend. While the mean $b/l_{fus}$ value of the jet is 0.89, this value is 1.40 for single piston aircraft.

In Fig. 5 extreme aircraft designs are presented according to wingspan/fuselage length ratios. In single-piston aircraft, the air racing aircraft- homebuilt aircraft, military trainers and aerobatics have low $b/l_{fus}$ values, while motor gliders, firefighters and agricultural aircraft have high $b/l_{fus}$ values. In twin-piston aircraft, light transport aircraft have low $b/l_{fus}$ values, while firefighters have high $b/l_{fus}$ values. In turboprop aircraft, the aircraft of regional airliners and executive transport aircraft (P.180 Avanti, Mitsubishi MU-2) have low $b/l_{fus}$ values, while firefighters, patrol aircraft, agricultural and STOL turboprop aircraft have high $b/l_{fus}$ values. In jets, the aircraft of the regional airliners, narrow body jets have low $b/l_{fus}$ values, while business jets and trainer jets have high $b/l_{fus}$ values.




**Single piston** **Twin-piston** **Turboprop** **Jet**

**Figure 5.** Some extreme examples in terms of $b/l_{fus}$ in different aircraft types

## 4. Conclusion

When power correlations obtained depending on the mass between both fuselage length and wingspan were examined, high correlations were obtained in turboprops and jets, good correlations in twin pistons and bad correlations were obtained in single pistons. The ratio of wingspan to fuselage length was high in single piston aircraft, while it was low in jets. For single-piston aircraft the $b/l_{fus}$ value is in the range of 1.04-2.25, with a mean value of 1.40. For twin-piston aircraft the $b/l_{fus}$ value is in the range of 0.88-2.14, with a mean value of1.30. For turboprop aircraft $b/l_{fus}$ value is in the range of 0.86-1.82, with a mean value of 1.21. For the jets $b/l_{fus}$ value is in the range of 0.61-1.27, with a mean value of 0.89. In single-piston aircraft, the air racing aircraft, homebuilt aircraft, military trainers, aerobatics, and air taxi aircraft have low $b/l_{fus}$ values, while agricultural aircraft and motor gliders have high $b/l_{fus}$ values. In twin-piston aircraft, the light transport aircraft have low $b/l_{fus}$ values, while firefighters have high $b/l_{fus}$ values. In turboprop aircraft, the regional airliner aircraft and executive transport aircraft have low $b/l_{fus}$ values, while firefighter aircraft, patrol aircraft, agricultural and STOL aircraft high $b/l_{fus}$ values. In jets, the regional airliner jets and narrow body jet airliner have low $b/l_{fus}$ values, while business jets and trainer jets have high $b/l_{fus}$ values. A finding on the recommendation of the reviewer has been added to the results section. In this study, although the size-mass relations are compared according to engine types, the common use of composite materials in commercial jets; The differences in aircraft mass, wingspan and fuselage length of old and new jets may be one of the future studies.

## Ethical approval

Not applicable.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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