# Analysing the "Northrop Grumman B2 spirit" aircraft's operational and design aspects in order to ascertain the issues related to flying wing concept in implementing as a commercial airliner

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***Abstract***— *The "flying wing concept" is a phenomenal innovation in the aviation industry which has revolutionized the preliminary perceptions of the subject. However the rapid industrial expansion of the same is restricted partially due to several aerodynamic complications such as maneuverability and stability when compared to the contemporary airframe designs. This paper presents a detailed analysis of the design characteristics of the subject and focuses on ascertaining the possible enhancements for the available design. The renowned heavy bomber B2 aircraft has been selected as the prototype for a full design analysis in implementing as a commercial airliner. The main objectives of the research would be to assess the complications of the flying wing concept which are related to the characteristics and the overall aerodynamics of the aircraft. The main focus of this research is to highlight the above issues and to suggest methods of overcoming those with experimental implementations and modifications. As this is a complex profile it is highly preferable to commence with a design comparison over hand of the analysis. This comparison is done respectively with the most commonly airborne civil aircraft Airbus A320. Further a scaled down model of the aircraft is expected to be physically evaluated at the educational wind tunnel at subsonic spectrum. As the aircraft is of tailless type, most of the control surfaces have been left for further research and B2 aircraft being a full wing aircraft, every implementation or modification should be executed without disturbing the structural integrity as well. Further, each enhancement done is focused on minimum complexity and is done with caution for not affecting the stability of the aircraft. With full design being analyzed the expectation is to go beyond the present conditions and to enhance the aerodynamic stability and the maneuverability while enhancing the overall performance of the flying wing concept.*

***Keywords****: Flying Wing, Aerodynamic performance & Stability, Commercial Airliner*

## I. INTRODUCTION

The concept of flying wing had been in play even before the First World War. William Dunne's flying wing design was given to the world before the world war but was still in the research stage. After 1915 Hugo Junkers' firm was able to build up a better design for the flying wing. The designs made for world war one was able to give a stable and greater leap in flying wing concept.

After the world war the flying wing concept was taken for consideration to be built for commercial airliners. With lest drag this concept was an ideal design to carry passengers in a larger number. With time the flying wing concept was kept aside in only for military purposes.

The flying wing concept is kept under research in the modern world such that there are new power sources to increase the efficiency of the concept. The latest accomplished design in flying wing Northrop Grumman Switchblade (2008) as a UAV project done in United States.

The strategic bomber B2 Spirit produced by the Northrop Grumman Corporation have proven to be the most effective design in the concepts of flying wing. After the production done in 1987 the bomber was introduced to service in 1997 April after Lockheed F-117 Nighthawk. . The most crucial option being the ability of stealth each design aspect have being done such that it does not affect the radar blindness.

As the B2 Spirit is still in service of United States Air force the confidentiality of the design philosophies are kept under critical surveillance.

The working ability of the aircraft being about 15,000 m of altitude and 11,000,000 m of range with only the internal fuel tank. With the ability of refuelling in mid-air 19,000,000 m with one refuelling. Thus any design configuration done is given proper consideration in guiding the flaws to be precise in above distance manoeuvring.

A complete specification analysis will be carried throughout this paper to take B2 aircraft as a case study and with respect to the findings in order to ascertain the issues related to flying wing concept giving the edge to enter civil aviation.

Figure 1. B2 Spirit Strategic Bombe

## II. METHODOLOGY

As per this study being a qualitative comparison of a military aircraft with a commercial aircraft in order to identify the design and operational flaws of the military aircrafts ability to achieve a flyable condition as a commercial airliner.

In order to achieve this firstly a comparison between the B2 spirit strategic bombers design and operational aspects and the most common airliner in the world Airbus A320 is carried out.

Secondly a critical analysis will be done under experts ideas regarding the performance of the B2 spirit and will be compared with the required performance for an airliner.

Finally a discussion is to be carried out the likelihood of the B2 aircraft to be a commercial airliner and improvements to achieve the objective of becoming a commercial purpose aircraft.


Figure 2. Airbus A320

## III. B2 SPIRIT STRATEGIC BOMBER

The B2 bomber aircraft is one of the phenomenal aircrafts which sustains abilities which gives it exceptional military skills. As per the military strategies the added advantages the B2 has are the design that complying with stealth. The characteristics of the B2 aircraft are improved much giving the strategic edge in military aspects, at the same time with which the aero dynamical characteristics are also improved.

*1) Advantages*

- The B2 aircraft is a flying wing concept aircraft which has a higher stability in air under sever conditions.
- The ability of this aircraft to fly a long range gives the possibility to cover a long distance flight without any lag.
- The higher fuel capacity of the aircraft and the ability to on-air refuelling brings up the factor to increase the range further.
- Ability to carry a heavier payload.

*2) Disadvantages*

- Lesser stability in landing and taking off.
- Hard manoeuvrability in air which respectively reduce the capacity of withstanding sudden atmospheric changes.
- Larger weight of the aircraft.

As per the advantages and disadvantages the B2 spirit has up raised to a level which the USAF have gained the strategic decision in commissioning the aircraft until 2040.

## IV. AIRBUS A320

A320 is the first aircraft with a single aisle which is used in short and medium distance routs. As the aircraft which is commercialized the most in the world the A320 is a still developing aircraft. Each year the Airbus Company expands its horizon for this aircraft by researching for improvements to make this aircraft stay in the skies for another longer years.

*1) Advantages*

- Increased exit limits.
- Advanced use of weight-saving composites.
- Optimized wing with 20% more efficient.
- Centralised fault display for easier troubleshooting and lower maintenance cost.
- Enhanced comfort for passengers.
- Advanced Navigation Technology

*2) Disadvantages*

- Life cycle of 48,000 landings which can be extended by heavy maintenance.
- No automated Fly-by-wires system.

With the given advantages and more, the A320 aircraft have gain its position as one of the best aircrafts to sustain in commercial aviation.

This gives the base for this study to take the A320 as a benchmark in building the path to develop the B2 spirit aircraft into becoming a commercial airliner. While overcoming the design flows of A320 aircraft and answering the uprising hazards of commercial aviation.

## V. PATH TO COMMERCIAL AVIATION

As the B2 aircrafts first purpose is to serve the military purposes all the specifications are built in total military aspect. Thus when the end of its commissioned time runs

out the military use decays. With which the aircraft will be grounded without usage. With the cost of building this aircraft it is a higher financial loss in grounding this aircraft after its intended work period is over as a military aircraft. As this is a strategic bomber with studies it is proven to be the most stable design of a bomber which the world will see through till its commissioned time.

In order to avoid the aircraft going into decay without having a proper use is unacceptable with its financial expenditure throughout its commissioned period. Thus to avoid this from happening and to gain the best out of the design aspects with this study it is considered to build up the path for the B2 spirit to gain its way in becoming a commercial airliner.

As for the fuel economy and range parameter reengineering of this aircraft may gain a better outburst in long duration flight with the least fuel consumption. With the higher speed and increased space inside it will develop a better environment for the passengers and will spare the time of the journey. Which will be efficient in both financial and productive work. This will be reflected in the airlines reputation of flight.

## VI. B2 VS A320 OPERATIONAL SPECIFICATIONS

Table 1. Specification Comparison

With respect to Airbus datasheets and Northrop Grumman datasheets.

| B2 Bomber | A320 |
|---|---|
| Power- F118 GE 100 engine | Power- CFM565 engine or IAE V2500 engine |
| Gross weight- 152,634 kg | Gross weight- 73,500 kg |
| Span- 52.5 m | Span- 35.8 m |
| Runway Length- 1981.2 m | Runway Length- 1676.4 m |
| Range- 11,100,000 m | Range- 650,000 m |
| Cost- $ 2 Billion | Cost- $ 97 Million |
| Accommodations- 2 | Accommodations- 150 |
| Max Payload- 18,000 kg | Max Payload- 16,600 kg |
| Mach- 0.85 | Mach- 0.78 |
| Fuel Capacity- 75,750 kg | Fuel Capacity- 18,700 kg |
| Max Thrust- 4*7,847 kg | Max Thrust-2*12,247 kg |

## VII. AIRCRAFT FACTORS TO CONSIDER WHEN SELECTING FOR COMMERCIAL PURPOSES

In basic aircraft designs at the stage of designing the final purpose of the aircraft is selected either military or commercial. In the modern world the military aircrafts are directed to other purposes after its number of commissioned years are completed. Some of these purposes are health and safety, search and rescue, firefighting, crop dusting and rarely commercial purposes. In the use of commercial purposes there are several factors to consider before enlisting.

- Customer and manufacturer demand
- Safety Protocols
- Physical and economic constraints
- Aircraft Regulations
- Environmental factors

All these factors should be considered whilst developing a military aircraft to engage in commercial purposes.

## VIII. EXPERT IDEAS

As this is a military strategic aircraft there have been an enormous amount of planning dun in developing the ideal design. The design is made for military purposes and military purposes only.

- According to Thompson the ability of B2 aircraft does not only stand in flying to a destination and return back but to face any sudden changes and improvise accordingly. The cost of manufacturing is proportional to the payload it can carry.
- As Pappalardo explains the next gen engines will be an adaptable engine. This will be designed with higher fuel economy and variable- cycle. The adaptability stands in reconfiguring the engine by itself accordingly with the situation.
- Related to the study by Cross the landing of the B2 is not difficult, particularly 2nd easiest to the F-15 and has the cushioning effect.

## IX. ADVANTAGES AND DISADVANTAGES OF B2 ENGINE

Table 2. Pros and Cons of F118 GE 100

| ADVANTAGES | DISADVANTAGES |
|---|---|
| Less noise due to greater mass flow | Greater complexity and need heavy blades |
| Lower total exhaust flow | Large diameter engine |
| More efficient for a useful range of subsonic speeds | More subjected to FODs and ice damage |
| Cooler exhaust temperature | Top speed is limited do to potential of shock waves to damage engine |

## XII. RESULTS

*A. Basic Calculations for B2*

*1) Velocity Calculation*

$$M = \frac{\text{Speed of free stream}}{\text{Speed of sound}} = \frac{Vs}{V}$$

$Vs = MV$ $Vs = 0.85*340.29$ m/s

$Vs = 289.2465$ m/s

*2) General Lift Coefficient*

Wing Loading= 329 kg/m$^2$

$$\text{Wing Loading} = \frac{\text{Gross weight}}{\text{Wing Area}}$$

$$\text{Wing Area} = \frac{152{,}634}{329} = 463.9331 \text{ m}^2$$

$$C_L = \frac{2mg}{\rho S V^2} = \frac{2*152{,}634*9.81}{1.225*464*(289.2465)^2} = 0.06297$$

In accordance with Northrop Grumman Wikipedia entry.

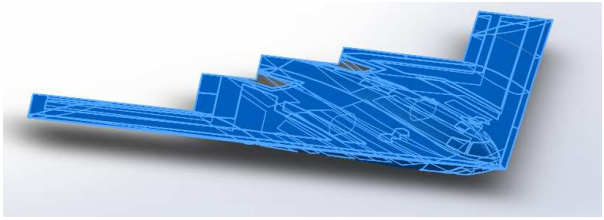

Figure 3. B2 Design specs

*B. Basic Calculations for A320*

*1) Velocity*

Maximum operating velocity: Vs= 180.056 m/s

*2) General Lift Coefficient*

Gravitational Acceleration: g=9.81 m/s$^2$

Wing Area: S= 128 m$^2$

Air Density: ϱ= 1.225 kg/m$^3$

$C_L = \frac{2mg}{\varrho S V^2} = \frac{2*73{,}500*9.81}{1.225*128*(180.056)^2} = 0.2837$

In accordance with Airbus datasheet.

## XIII. DISCUSSION

With the results obtained by the comparison the B2 as a military aircraft and A320 as a commercial aircraft were compared in their intended usage and drawbacks. There are several reasons the A320 being the world's best-selling narrow body aircraft. With compared to those reasons the performance of B2 is compared.

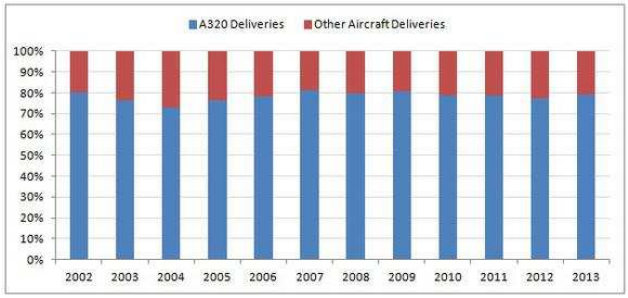


Figure 4. A320 Deliveries against other Aircraft Deliveries

There are several factors that gives an added advantage to A320 aircraft as a commercial aircraft. These advantages build up several facts that it requires to implement an aircraft in commercial use.

- Spacious aisles
- Efficient service doors
- Larger cargo area with easy access
- Most cabin baggage space in the class

By reengineering the outstanding design of the B2 aircraft under the required specifications it has the ability in being adopted to commercial aviation.

As the basic objectives of the B2 spirit being,

- Serve as a multi – role bomber
- Stealth
- Ability to fly long missions

It has shown exceeded expectations in its missions according to USAF data library.

When considering the comparison of operational specifications between the B2 and A320 the spirit has some of its characteristics as added advantage in being a commercial airliner.

According to the comparison the B2 spirit is having non-afterburning turbo fan engines which doesn't bring out a disadvantage as the 320 is also having an engine without afterburners. In modern engines turbofan engines with high bypass is not in need of afterburners. The gross weight of the B2 spirit being larger than the A320 might be a disadvantage such that it may cause in reduction in fuel efficiency. If this matter was able to be avoided or modified such that the fuel economy gets lowered.

When the runway length which is required for an optimum take off is considered the B2 has a much longer runway requirement. This can become a disadvantage in converting into a commercial airliner. The basic requirement of longer runway is proportional to the weight of the payload and the gross weight of the aircraft. The heavier the aircraft is to be the longer the runway needed to take off. The higher weight of the B2 bomber may increase the amount of runway needed until the gross weight is to be reduced in any means possible. As per the longest runway need by a cargo aircraft is 3,151 m by Antonov- 225. The reason being as a cargo aircraft it needs much strength in handling the weight of the cargo. As for the B2 in military as it works as a heavy bomber, basically equivalent to a commercial cargo aircraft. When interchanging the use of the aircraft from military to commercial there might be possible means in reducing weight with this aspect.

The biggest advantage of the B2 aircraft is its range of flight and the ability of air to air refuelling. With this advantage it gives the ability to avoid the transits in longer flights. In another aspect it may not uplift the ergonomic principles of long duration flights. As per the fuel economy with the continuous flight it will avoid the high fuel consumption in starting of the engine for several times.

Figure 5. Air to Air Refuelling

As per the cost of building the aircraft is high the usage of the aircraft should be reasonably economical. Thus the cost of B2 builds up the background of needing the longest flight time to this strategic bomber until it is grounded from service. For the military purposes the spirit is commissioned until 2040 which the expenditure of building is kept in its intended use. As for a single product of B2 spirit the use of higher number of flying years will give the advantage of accomplishing its total cost.

In military use even though the accommodation available is 2 with the ability of max payload being 18,000 kg can be covered by the proper use of space and weight with respect to A320s accommodation of 150 and max payload being 16,000 kg. With proper reengineering of space and payload weight it can be modified into gain ability to improve in commercial aviation. In comparison with A320 the reengineering could be done with the outcome of,

Average global body weight = 62 kg

Load generated due to passengers = 62 * 150 = 9,300 kg

Max. Payload with respect to A320 = 16,600 kg

Load saving = 18,000- (7,300+9,300) = -1,400 kg

In order to achieve the excess 7,300kg which require to accommodate 150 passengers may be able to achieve with proper managing of fuel capacity. This may affect in the range of flight but with on-air refuelling this disadvantage might be avoided. At the same time the refuelling might put passenger safety at risk thus violating the laws of air with proper modification this can be avoided.

The ability of B2 to fly at o.85 Mach gives the advantage of achieving higher range in lesser time compared to 0.78 Mach of A320. With this speed the number of flights that can be flown could be increased if the regular maintenance and proper flying conditions are acquired before and after a flight.

Fuel capacity being extremely high gives the edge of having a higher range without interrupted flight. When taking into commercial aviation if the range is neglected the fuel capacity could be reengineered for more space or reduced gross weight which may affect in reduction of fuel consumption.

When considering the major factors that effect in implementing an aircraft for commercial aviation customer and manufacturer demand can be highly affective. In modern days the customer demand is highly evaluated with which the airlines financial stability depends on. As per the customer demand in normal flight plans most passengers are deemed to have a flight without transit. With this aircraft implementation the customer demanded range could be easily achieved. As the demand of aircrafts get higher by the day due to increment in destinations and increment in transits towards a destination the air traffic gets higher.

Whilst by implementing a design with longer range will be able to cover the same distances and destinations without over filling the skies with more and more aircrafts which may in the other hand may disrupt in global order.


Figure 6. Demand in no. of aircrafts in the world according to Global Market Forecast

As the main intentions of a military aircraft being safety and strength the safety protocol is easy to achieve. But for commercial aircrafts there are many safety protocols to achieve as without it the lives of the passengers may be in jeopardy. For example in any accident the exits should be sufficient for the passengers and crew to evacuate within 90 s. Whilst the reengineering is being done the number of exits should be calculated such that this regulation is being met.

For another aspect being physical and economic constraints when A320 is taken into consideration each year the airbus company invests 100 million euros to achieve its maximum efficiency with each development it can acquire. The airbus company have gained various aerodynamic refinements which have brought additional reductions in drag for better fuel efficiency and lower emission. As the B2 spirit is specially designed for high subsonic speeds it has a higher fuel economy comparatively. With improved weight conditions and propagated aerodynamic design the fuel consumption can be reduced. The F118 GE 100 engine has a Thrust Specific fuel Consumption value of 0.67 at the same time A320 having the IAE V2500 engine has a Thrust Specific Fuel Consumption value of 0.35. With a higher TSFC value the B2 engine is less economical.

Figure 7. F118 GE 100 engine

As per the aircraft regulations after any required changes the B2 spirit must be accepted by the FAA part 25 which will give the proper authentication for the aircraft to transport passengers. As for the environmental factors which may affect by aircrafts are,

- Climate change
- Noise
- Air quality
- Radiation exposure

With each aircraft that flies there are several environmental factors that get affected in a harmful way. In accordance with the above mentioned factors the B2 spirit has corresponding characteristics which are avoidable and unavoidable.

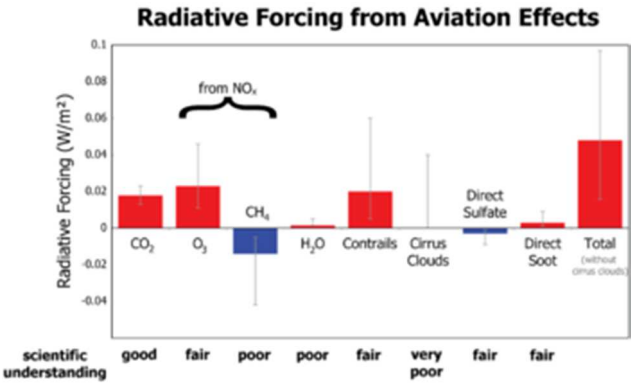


Figure 8. Environmental impact of aviation estimation by IPCC

As for the climate change this occurs due to emission of Carbon dioxide, Oxides of Nitrogen, water vapour and contrails, Particulates and Greenhouse gases. With the B2 bomber some of the emission pollution factors are avoided. For this the reason being as this aircraft is a strategic stealth bomber the design is made in such a way with less emission for less detectability. As the B2 bomber being a stealth aircraft, purposely brings up the effect of noise thus have reduced the noise generated. In means of air quality the Tetra Ethyl Lead found in leaded avgas and its combustion products are neurotoxins which are scientifically proven to interfere with brain development of children. As the B2 spirit engine is using a Kerosene based avgas the emission have been redundant of Tetra Ethyl Lead in fuel. As for the radiation exposure, flying for long hours in high altitudes expose the human bodies to cosmic rays nearly up to 10 times as the sea level exposure. Aircrafts flying near to the geomagnetic poles are particularly at risk. As the B2 spirit flies for longer hours this exposure to radiation may reflect in a deprived state. As the stealth bomber is designed such that many of the waves get deflected this might be a considerably safe path.

While considering all these factors the B2 has its pros and cons in being developed in to a commercial airliner which compared to A320 the most common airliner in the globe.

## XIV. CONCLUSSION

In accordance with this study all the factors related to what an aircraft should poses in order to be airworthy as a commercial airliner is presented throughout.

With respect to above data provided it is stable that the B2 spirit strategic bomber has the potential to be a commercial airliner if it has been through a proper remodelling and reengineering process which could ultimately bring the carrier stability in both military and commercial aspects.

As the B2 spirit has its unique characteristics which normal aircrafts does not hold it gives the edge for the aircraft to being a better airliner.

With the large instability conditions it will be in need of major stability control in larger CofG variations due to not carrying steady cargo as an airliner.

Under this aspects as this aircraft being a property of the US government if or any major modification is done the FAA should be directly notified. As for the benchmark any change done in different horsepower engine, a different pitch propeller, a change in basic design, etc. is a major modification.

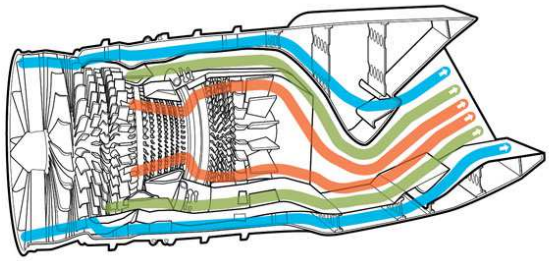

Figure 9. NEXT-GEN ADAPTABLE ENGINE

With proper remodifications the B2 aircraft will be a tremendous leap in modern commercial aviation. With extreme end engines the time parameter of a journey will be reduced to a minimum and the crucial factor of emergency transport will be effective.

With the large space the passenger comfort and ergonomic principles will be full filled to a higher gradient in coming to its peak.

With the reengineering the fuel economy stays at the same stage or get reduced the final product will be a financial risk breaker in aviation world.

As this being a military aircraft having the safety of withstanding war the safety and hazard mitigation will be extremely high without much exertion.

This turnover will build the aviation world much more economical and comfortable at the same time.

## XV.FUTURE STUDY

- CFD analysis of aerodynamic profile of B2 profile and comparison with A320 profile.
- Improving the stability of the B2 spirit in varying CofG conditions.
- Developing proper spacing system for accommodation for maximum amount of passengers.
- Improving the fuel efficiency of the aircraft with the propagation of gross weight as a commercial airliner.
- Developing methods of reducing the maximum take-off weight of the aircraft without affecting the integrity of the structure.

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