Case Study: Junkers 87B 'Stuka'

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CONTENTS

1 ABSTRACT

This case study examines the Junkers Ju 87 'Stuka', a German dive bomber designed and deployed during the Third Reich; specifically, the study focuses on the 87B, which was the main Stuka variant in use between 1938 - 1941. The study begins by giving context for the Stuka, and an examination of the motivations behind dive bombing, before proceeding to an in depth analysis of the construction and aeronautic performance of the Stuka. Where possible primary source material has been used. All other evidence has been gathered from secondary historical commentary; and all calculations have been informed by technical reports and textbooks.

When calculating operational parameters for the Stuka, it was necessary to consider that the Luftwaffe deployed the Stuka in the Western and Eastern fronts, as well as the Desert and Mediteranean theatres. Accordingly, calculations have been performed for the hottest and coldest temperatures at which the Stuka operated, as well as using meteorological data from the Battle of Britain as a model for ideal operational conditions.

2 Junkers Ju 87

The Junkers Ju 87, the development of which was lead by Hermann Pohlman, began development in 1933. First flown in 1935 (Weal 1997, p. 9), the Stuka succeeded a previous Junkers Ju 47 K dive bombing design, which had been rejected by the German Reichswehr (defense ministry) as too expensive, and replaced the Heinkel He 50 as the dive bomber of choice for the Luftwaffe. Heinkel had also been developing a competing design, the 118, but failed to win the contract when their design could not demonstrate the prequisite ability to dive at a 90° angle, disintegrating during flight (Killen 1967, p. 68-69) and forcing the pilot and judge of the competition, Ernst Udet, to bail out.

The dive-bomber design emerged as a solution to the need for precision bombing of tactical objectives during the later stages of WW1, and was eventually replaced by improvements in bomb sighting, increased bomb payloads, and guided weaponry. Dive bombers would align themselves laterally before engaging in a dive towards a target, descending to a given height to release their payload and then pull out of the dive. Diving aligned the velocity of the aircraft in the direction of the target, and reduced the distance travelled from release to impact; this significantly reduced targeting complexity, and correspondingly shrank the circular error probable (CEP), the region in which 50% of munitions were predicted to land. In comparison, horizontal bombers using unguided bombs had to compensate for a parabolic bomb trajectory where a bomb had horizontal velocity at launch and was acted upon by drag and gravity during flight. Even in calm weather, using tachometric bombsights, horizontal bombers during WW2 had large CEPs and could not accurately hit small targets, being more suited to mass scale interdiction bombing 'area-denial' sorties.

The increased accuracy offered by dive bombing was tactically significant, enabling both close air support of ground forces in combined arms operations without risk to engaged units, as well as accurate attacks against shipping which had been difficult to accomplish with interdiction bombing; however, diving towards targets placed aircraft at increased risk from surface fire, and steep diving maneuvers limited payload weight and placed increased stress on the craft. Dive bombers were also targets of opportunity for enemy fighters, since their diving manoeuvres were predictable and broke from protective formations, and they could not match the manoeuvrability or speed of fighter craft; this, in conjunction with improvements in bombing technology, lead to the decline of the dive bomber after WW2.

3 General Design of the Ju 87B

3.1 Body

The Stuka was a twin seater monoplane, with the fuselage acting as an anchor for two spars, one for each wing, which served to distribute the load caused by lift and enable the cantilever of the wings. The use of an anchored spar had been pioneered by Hugo Junkers in 1915 (Nasa 2016) in the Junkers J 1, who found that the improved strength provided sufficient support to allow for an all metal design with cantilevered wings. Single wing designs based on this principle then superseded the previous biplane designs, which were hampered by aerodynamic interference between the two wings, as well as by increased drag from the supporting structures necessary to reinforce the wings (Peery 2012, p .37). Due to a complex wing shape, the Stuka used the same principle of anchoring spars in the fuselage, but required two spars instead of one.

The Stuka's fuselage was constructed from two oval chassis sections, which were joined using rivets along the longitudinal axis. Internally, each section was attached to a series of longerons which ran the longitudinal length of the Stuka, and which were attached to a series of u-shaped frames. The use of longerons as opposed to stringers served to reinforce the Stuka for the increased load experienced during pullout from the diving maneuver (Peery 2012). Additionally, to further increase the structural integrity of the tail, which experienced extreme load during pullout, significantly more frames were used in the tail section than the body (Figure. 1).

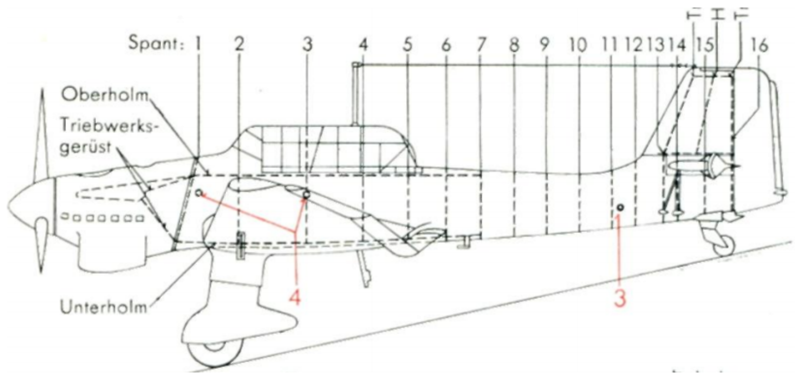

Figure 1: Frame or rib (German: *spant*) distribution in the Stuka body (Luftwaffe 1939)

3.2 WINGS

The Stuka had low mounted polyhedral wings which were formed from two spars, and consisted of three sections; a central section and a port and starboard section. The central section was depressed to an anhedral angle of 8 degrees, while the two other wing sections had a dihedral angle of 12 degrees. The total wingspan was 13.8m, giving a total wing area of 31.90m^2; the length of the anhedral part of the wing on one side of the Stuka was 1.05m, while the dihedral part was 5.5m (approximate) [1] . The justification for using an inverted gull-wing is not clear from documentation, since the polyhedral design complicated manufacture and added weight; however, a similar wing configuration can be found in the 1940 F4U Corsair, where the polyhedral design allowed shorter landing gear while still providing clearance for a 4m propeller (Sibila 2016) - the Stuka's own propeller was 3.5m. As the landing gear of the Stuka were fixed, reducing their length would reduce drag. Another effect of the design was to cause the low mounted wings to protrude from the fuselage at a perpendicular angle, which would reduce interference between the wing and the body (Hartshorn 1931, p .203). A final reason for the design could have been to improve the pilot's visibility of the ground; the cockpit was located above wings of the Stuka,

[1] No exact values could be found for wing sections, so lengths were calculated based on known wingspan and cockpit width, and proportions from scale drawings found in Junkers manuals (Luftwaffe 1939)

and so the low mounting and anhedral angle would act to remove the wings from the pilot's field of view (Guardia 1914, p .16).

3.3 Control Surfaces

Offset from the trailing edge of the wing were full-span ailerons which were operated using hydraulics. This uncommon design, invented by Otto Maders and known as a "Junkers flap" (), allowed airflow to pass between the wing and the aileron even when the aileron was retracted. The main effect of the flap was to "influence the air flow around the main airfoil so that the airfoil carried a much greater load without stalling" (Wenzinger 1938, p .14), and in addition to reducing stall, the design provided high lift and low drag when the Stuka was climbing. A negative side effect was that at higher speeds the offset flap increased drag, and therefore reduced the maximum velocity of the Stuka.

In addition to the Junkers flap, the Stuka had dive brakes, and an automated pullout system.

3.4 Materials

The body and wings were made principally from duralumin, an aluminum alloy composed from copper, magnesium, and manganese [2], except in cases where parts were required to be more resilient to daily wear, in which case stronger Elektron alloys were used to reduce the need for maintenance (Guardia 1914, p. 15). The outer sheeting was also made from duralumin, and parts that underwent greater stress, such as bolts and the canopy frame, were constructed from steel.

3.5 Propulsion

Thrust for the Ju 87B was provided by a variable pitch 3.5m Jumo-Hamilton HPA III propeller which was automatically regulated, and which was powered by a 12-cylinder Jumo 211D engine producing 883kW. The engine was water-cooled, being fed from a 10 litre tank (Junkers 1941, p .7), and cooling was provided by two radiators positioned above and below the engine block so that air drawn by the propeller would pass over the radiators; this cooling action could be controlled to some extent using cooler flaps operated by the pilot. Fuel was injected into the engine from two 240-liter tanks, and in case of injector failure, the gunner could hand operate a manual pump. The two fuel tanks were located beneath the cockpit, which was protected from the engine and tanks by an asbestos firewall. Maximum safe engine temperature was reduced as altitude increased (Figure 2), limiting the work that could be done as the Stuka climbed. Typically the Stuka operated at 4500m, and it was limited to a maximum service ceiling of 8000m due to its unpressurized cockpit.

(Guardia 1914, p .16). The dry weight of the engine was 638kg, giving the 87B an overall unloaded weight of 2760kg, which could be increased up to a maximum of 4400kg; this allowed for a total possible 500kg of ordnance when accounting for crew and fuel.

[2] Unfortunately, precise values for the alloy could not be located, but the general composition of duralumin is 93.5 - 95% aluminum, 4% copper, 0.5 - 1.0% manganese, and 0.5 - 1.5% magnesium (Wardlaw 1933, p. 102-103)

Kühlstoff-Höchsttemperaturen

Flughöhe km	0	1	2	3	4	5	6	7	8	9	10
Austritt ° C	115	112	109	106	103	100	97	94	91	88	85

d. h. je 1000 m 3° C niedriger.
Bis zur Nennleistungshöhe vorübergehend 120° C zulässig.

Figure 2: Maximum temperature (in Celsius) of engine against altitude (in km) of Jumo 211 engine (Junkers 1941, p .11)

3.6 Calculations

3.6.1 Lift

For the purposes of simplification the anhedral portion of the wing is treated as flat, since no mathematical model could be found to calculate a polyhedral wing with anhedral and dihedral parts. Calculation is done for temperatures of -20.7 C (Battle of Stalingrad low (Hartshorn 1988, p. 731)) and 23.6 C (Battle of Britain high (*Meteorological data, Oxford, 1853 - 2016* 2016)). Given these conditions, the following values are used for calculation.

$$L = \frac{1}{2}\,\rho V^2 S_{ref} C_L \qquad (1)$$

L	Lift
ρ	Density
V	True Airspeed
S_{ref}	Reference Area
C_L	Lift Coefficient

3.6.2 Drag

3.6.3 Speed

3.6.4 Range

4 Testing, Development, and Production

4.1 Testing and Development

The prototype of the 87B was the predecessor Ju 87A, which went through a number of successive iterations during its development. The initial design, the V1, featured a Rolls-Royce Kestrel engine and a twin tail-fin (Figure. 3)

4.2 Production

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Figure 3: The Ju 87A-V1 with twin tail fin and Kestrel engine (Zoeller 2016)

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