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MULTI-CRITERIA ANALYSIS OF MODERN MILITARY TRANSPORT AIRPLANES

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Abstract:
An airplane is a fixed-wing aircraft which is propelled forward in presence of thrust which is developed by a jet engine, rocket engine or a propeller. The main categories of airplanes are military, transportation of people and goods, research or recreation. A multi-criteria analysis is comprehensive in order to discover the best military transport aircraft from the ones I proposed to study, all the quatitative and qualitative criterions being chosen objectively, the main criterions being relevant and important for the aircraft. The purpose for a multi-criteria analysis is to discover the best quality-price relation for any of the aircraft, making it a trusted method in any acquisition process. To this end, an overview of the features characteristic of four such airplanes is provided. Based on that, a number of assessment criteria and their weighing are established in order to create an assessment matrix and a hierarchy of the four transport airplanes.

Key words: airplanes; aircraft; military; transport; Wright; flight; Lockheed; criterion

1. Introduction

An airplanes is a fixed-wing aircraft which is propelled forward in presence of thrust which is developed by a jet engine, rocket engine or a propeller. Airplanes come in a variety of shapes, sizes or wing configurations. The main categories of airplanes are military, transportation of people and goods, research or recreation. Nowadays, most of the airplanes are controlled by one or two pilots, but there are some modern prototypes of airplanes which are remotely or computer-controlled, such as drones.

The first airplane was invented and flew by the Wright brothers in 1903, and it is recognized as the first controlled and sustained heavier-than-air powered flight. They followed the George Cayley's research, dating from 1799, when he set the first concept of a modern airplane. Another pioneer who studied heavier-than-air flight is the German scientist Otto Lilienthal, between 1867 and 1896. Despite of the limited use of the airplanes in the First World War, the technology continued to develop with big steps, so during the Second World War, the airplanes were present in every major battles.

The first jet aircraft ever built was the German Heinkel He 178, made in 1939. Its first flight took place on 27 August 1939, and it was piloted by Erich Warsitz. In 1936, a young engineer named Hans von Ohain created a patent using the exhaust from a gas turbine as means of propulsion. In fig. 1 it is represented the model of the Heinkel He 178, as it was presented by Hna von Ohain.

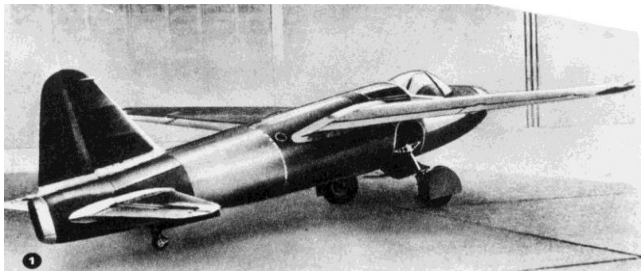

Figure 1.

He presented the idea to Ernst Heinkel, who decided to help develop the patent. Hans von Ohain succeded to demonstrate his first engine, in 1937, named Heinkel HeS 1, and after a short period of time, the started quickly to test a similar engine on the aircraft. The He 178 was designed based on the von Ohain's third engine concept, named HeS 3, which burned diesel fuel. The final result was a small aircraft with a metal made fuselage, which had a conventional construction and configuration. The jet intake was positioned in the nose, and a tailwheel undercarriage was fitted due to safety reasons. Considering the main landing gear, it was created to be retractable, but during the flight trials, it remained blocked in "down" position.

The aircraft completed its first flight on 27 August 1939, just days before Germany started invasion over Poland. The test pilot was Erich Warsitz, who was the pilot who flew the rocket powered airplane, named Heinkel He 176, which had the first flight in June 1939. In fig.2 it is represented the model of the Heinkel He 176, which can be seen in the Berlin train station.

Figure 2.

One of the most important and used airplane categories which developed from the first aircraft ever built, is represented by military transport aircraft. This type of aircraft are used to airlift weapons, troops and any kind of military equipment to support military operations. The missions during which the military transport aircraft are used are both strategic and tactical missions, and also civil emergency relief missions.

The main characteristics which define the fixed-wing transport aircraft are range capability and strategic or tactical airlift, reflecting the needs of the land forces which are supported. The first appearance of the military transport airplanes was during the Second World War, when major advances in this field were made. Parachute droops were the first missions of the transport aircraft, pioneered by the Soviet Union in the 1930s, but the first to use this technique operationally was the Luftwaffe, during the Crete invasion, in which 15.000 parachute and airborne troops were landed on the island by 80 gliders and 700 transport aircraft. One of the developments of the war which had no continuing place was the troop-carrying glider, but the transport fixed-wing aircraft was only at the beginning of the development. The first real transport airplanes were built by Germans, but the American industry made it what it is today,

with the production of the Douglas C-47 Skytrain and DC-3, which were the pivots of the tactical air transport in every Allied war.

From the Second World War to our days, the needs of the troops during the was changed, but the main purposes remained the same, and the way they are accomplished even more. Huge developments were made in aeronautical field, and now, the main criterion of the military transport aircraft is not only range, but maximul speed, cruise speed, powerplant, serive ceiling and more.

2. Transport Airplanes Description

In order to understand all the characteristic features of the selected airplanes, the chapter gives a brief description of the aircraft elected. The reasoning of choosing these airplanes is that they represent the top of the aeronautical industry from United States of America and Russia, from different periods of time, making them the best representants of these industries from 1980s until 2020.

2.1. C-5 Galaxy

The Lockheed C-5 Galaxy is a military transport aircraft, which was originally designed by Lockheed, and at this moment upgraded by Lockheed Martin. It represents, for the United States Air Force, a heavy intercontinental-range strategic airlift pivot, which can carry oversized or outsized loads, covering all air-certifiable cargo. The Lockheed C-5 Galaxy is one of the largest modern military aircraft.

The first model was delivered on 17 December 1969. The first mission of the C-5 Galaxy was on 9 July 1970, during Vietnam War. C-5 Galaxys were used to transport troops and equipment, including tanks and, in some cases, small aircraft, throughout the final years of the Vietnam War. Several C-5 Galaxys were used prior the Fall of Saigon(mission which had as goal to capture Saigon, the capital of South Vietnam), during the evacuation efforts. During these mission, one of the C-5A Galaxy crashed while transporting an unknown number of orphans, the accident killing over 140 of them.

Another conflict during C-5 Galaxy proved its capabilities was Yom Kippur War, the war of Istrael and United States of America against a coalition of some Arabic States, led by Syria and Egypt. During this conflict, C-5 Galaxys were used to deliver critical supplies of ammunition, to replace weaponry and to deliver other forms of aid to Israel.

On 24 October 1974, a C-5 Galaxy aircraft was used to drop an air-launched ballistic missile, during a test under the supervision of "Space and Missile Systems Organization". The program was dropped-of, and the aircraft used during the test was retired to the Air Mobility Command Museum at Dover Air Force Base.

The C-5 Galaxy was also been used during the development of the stealth fighters program, carrying partly disassembled aircraft, leaving no clue of their cargo.

General characteristics	Performance
• Crew: 7 typical (aircraft commander, pilot, 2 flight engineers, 3 loadmasters) ; 4 minimum (pilot, copilot, two flight engineers) • Capacity: ○ 36 master pallets 463L, 281,000 lb (127,459 kg) • Length: 247 ft 1 in (75.31 m) • Wingspan: 222 ft 9 in (67.89 m) • Height: 65 ft 1 in (19.84 m) • Wing area: 6,200 sq ft (580 m^2) • Empty weight: 380,000 lb (172,365 kg) • Gross weight: 840,000 lb (381,018 kg) • Max takeoff weight: 920,000 lb (417,305 kg) • Fuel capacity: 51,150 US gal (42,590 imp gal; 193,600 l) • Powerplant: 4 × General Electric CF6-80C2 turbofan engines, 51,000 lbf (230 kN) thrust each	• Maximum speed: 462 kn (532 mph, 856 km/h) • Maximum speed: Mach 0.79 • Cruise speed: 450 kn (520 mph, 830 km/h) / M0.77 • Range: 4,800 nmi (5,500 mi, 8,900 km) with a 120,000 lb (54,431 kg) payload. 2,300 nmi (4,260 km; 2,647 mi) with maximum cargo capacity. • Ferry range: 7,000 nmi (8,100 mi, 13,000 km) with no cargo on board. • Service ceiling: 41,000 ft (12,000 m) at 750,000 lb (340,194 kg) • Rate of climb: 2,100 ft/min (11 m/s) • Thrust/weight: 0.26 • Take-off run: 5,400 ft (1,646 m) • Landing run: 3,600 ft (1,097 m)

Table 1

In table 1, they are presented the main characteristics of the C-5 Galaxy, from which 6 of them were selected to create the multi-criteria analysis presented in Chapter 3.

2.2. Airbus A400M Atlas

The Airbus A400M Atlas is a four engine turboprop military transport aircraft, designed by Airbus Military as a tactical airlifter with strategic capabilities to replace all older transport aircraft, such as the Lockheed C-130 Hercules or the Transall C-160. In term of size, it is positioned between the C-130 and the Boeing C-17. The A400M is able to use rougher landing strips than the other two aircraft mentioned above, and it can carry heavier loads than the C-130. The A 400M Atlas can perform medical evacuation when it is fitted with appropriate equipment, and also it can perform aerial refueling.

On 29 December 2013, the French Air Force used the A400M in its first operational mission: during Operation Serval(a French military operation, in Mali, which had the aim to oust Islamic militants from the northen part of Mali), the aircraft had to fly to Mali to support the main course of action during French offensive maneouvres. In March 2015, the A400M completed its first mission under the RAF(Royal Air Force) service, as a cargo plane to RAF Akrotiri, Cyprus.

Between September and October 2017, A400Ms from Germany, France and United Kingdom were involved in the disaster relief operations in Carribean, following Hurricane Irma, transporting helicopters, water, food or other aid supply, even evacuating stranded people.

General characteristics	Performance

• Crew: 3 or 4
• Capacity: 37,000 kg (81,600 lb)
  ○ 116 fully equipped troops / paratroopers
  ○ up to 66 stretchers accompanied by 25 medical personnel
  ○ cargo compartment: width 4.00-metre (13.12 ft) x height 3.85-metre (12.6 ft) x length 17.71-metre (58.1 ft) (without ramp 5.40-metre (17.7 ft))
• Length: 45.1 m (148 ft 0 in)
• Wingspan: 42.4 m (139 ft 1 in)
• Height: 14.7 m (48 ft 3 in)
• Wing area: 225.1 m^2 (2,384 sq ft)
• Empty weight: 76,500 kg (168,654 lb) ; operating weight
• Gross weight: 120,000 kg (264,555 lb)
• Max takeoff weight: 141,000 kg (310,852 lb)
• Fuel capacity: 50,500 kg (111,300 lb) internal fuel
• Max landing weight: 123,000 kg (271,200 lb)
• Powerplant: 4 × Europrop TP400-D6 turboprop, 8,200 kW (11,000 hp) each
	• Cruise speed: 781 km/h (485 mph, 422 kn) at 9,450 m (31,000 ft)
	• Initial cruise altitude: 9,000 m (29,000 ft) at MTOW
	• Range: 3,300 km (2,100 mi, 1,800 nmi) at max payload (long range cruise speed; reserves as per MIL-C-5011A)
	  ○ Range at 30-tonne payload: 4,500 km (2,450 nmi)
	  ○ Range at 20-tonne payload: 6,400 km (3,450 nmi)
	• Ferry range: 8,700 km (5,400 mi, 4,700 nmi)
	• Service ceiling: 12,200 m (40,000 ft)
	• Wing loading: 637 kg/m^2 (130.4 lb/sq ft)
	• Tactical takeoff distance: 980 m (3,215 ft), aircraft weight 100 tonnes (98 long tons; 110 short tons), soft field, ISA, sea level
	• Tactical landing distance: 770 m (2,530 ft) (as above)
	• Turning radius (ground): 28.6 m

Table 2

In table 2, you can see all the main characteristics of the Airbus A400M Atlas, in order to understand the goals of the aircraft, and the way they changed during the service time.

2.3. IL-76MD Candid

IL-76MD Candid is a strategic four-engine turbofan airlifter, which can complete a big variey of missions. It was firstly designed as a commercial airplane, in 1967, as a replacement

for the Antonov An-12. Military versions of the IL-76MD Candid are widely used in Asia, Europe and Africa, 193eing used as a command center or aerial refueling tanker.

The IL-76 Candid was designed as a commercial freighter for ramp-delivered cargo, mainly for heavy and outsized items unable to be transported otherwise. It has also been used as an emergency transporter for civilian evacuations, as well as disaster relief or humanitarian aid around the world. Due to its ability to operate from unsolved runways, it had been very useful in undeveloped areas.

The Soviet Air Force were supplied with first aircraft in June 1974. During the Afghanistan War, between 1979 and 1991, the IL-76MD Candid completed 14.700 flights, transporting 315.800 tons f freight and 786.200 troops. The IL-76MD transported 74% of the freight and 89% of Soviet servicemen that were airlifted.

Because rebels were unable to shoot down any of the IL-76MD, they changed their tactics trying to damage them during takeoffs or landings, so the IL-76MD Candid were often hit with heavy machine guns or shoulder-lauched missiles. Even so, they did not suffer much damage due to the strong airframes and they remained operational until the end of the war.

In 2006, civilian users in Russia were using 108 IL-76MD Candid while the Russian Air Force had about 200.

General characteristics	Performance
• Crew: 5 • Capacity: Il-76M 42,000 kg (92,594 lb) ; Il-76MD 48,000 kg (105,822 lb) ; Il-76MD-90A 60,000 kg (132,277 lb) • Length: 46.59 m (152 ft 10 in) • Wingspan: 50.5 m (165 ft 8 in) • Height: 14.76 m (48 ft 5 in) • Wing area: 300 m^2 (3,200 sq ft) • Empty weight: 92,500 kg (203,928 lb) Il-76TD-90 92,000 kg (202,825 lb) Il-76MD/TD 104,000 kg (229,281 lb) Il-76MF/TF • Max takeoff weight: 195,000 kg (429,901 lb) 170,000 kg (374,786 lb) Il-76M/T 190,000 kg (418,878 lb) Il-76MD/TD 210,000 kg (462,971 lb) Il-76MF/TF • Powerplant: 4 × Soloviev D-30KP turbofans, 117.7 Kn (26,500 lbf) thrust each [83]	• Maximum speed: 900 km/h (560 mph, 490 kn) • Maximum speed: Mach 0.82 • Range: 4,000 km (2,500 mi, 2,200 nmi) Il-76MD-90A with 60,000 kg (132,277 lb) payload. 5,000 km (3,107 mi) Il-76MD-90A / TD-90VD with 52,000 kg (114,640 lb) payload. 4,000 km (2,485 mi) Il-76M/T with 52,000 kg (114,640 lb) payload. 4,400 km (2,734 mi) Il-76MD/TD with 52,000 kg (114,640 lb) payload. 4,200 km (2,610 mi) Il-76MF/TF with 52,000 kg (114,640 lb) payload. • Ferry range: 9,300 km (5,800 mi, 5,000 nmi) Il-76MD-90A with no payload. • Service ceiling: 13,000 m (43,000 ft) • Thrust/weight: Il-76: 0.228–0.252; Il-76M/T 0.282; Il-76MD/TD 0.252; Il-76MF/TF 0.228 • Minimum landing run: 450 m (1,476 ft) with thrust reversers

Table 3

In Table 3, they are presented the characteristics of the IL-76MD Candid, from which 6 of them were selected during the multi-criteria analysis.

2.4. Antonov An-124 Ruslan

The Antonov An-124 Ruslan is a strategic airlift quadjet designed in the 1980s in Ukraina, by the Antonov design bureau. The An-124 was, for thirty years, the largest gross weight cargo airplane and the second largest operating cargo aircraft, until the Boeing 747-8F. Still, the An-124 represents the largest military aircraft in current service.

The An-124 was designed for air dropping of large and heavy size cargo and for long-range delivery, including troops, machines or equipment. The development of the aircraft begun in 1979. The An-124 Ruslan completed its first flight in December 1982 and it entered in service in January 1986. The An-124 was Accreditated as a civil aircraft in 1992.

The high performance of the An-124 and its unique transport capabilities have been proven in the numerous operations it took part in. The aircraft fulesage presents a double- deck layout. The upper deck is represented by the troop cabin, with 88 seats, the relief crew compartment and the cockpit. The cargo hold is on the lower deck. The flight deck has crew positioned arranged in pairs of six spots: the pilot and the copilot, the navigator, the communications officer and tho flight engineers. In the lobby deck is located the loadmaster's station.

The An-124 is designed with a thick(12%) swept-back super-critical wing and, consequently, it was given a high aerodynamic effiency, in conclusion, a long flight range.

General characteristics	Performance
• Crew: 6 (pilot, copilot, navigator, senior flight engineer (+flight engineer, radio man) + 2 loadmasters) • Capacity: 88 passengers in upper aft fuselage, or the hold can take an additional 350 pax on a 194alletized seating system / 150,000 kg (330,693 lb) • Length: 69.1 m (226 ft 8 in) • Wingspan: 73.3 m (240 ft 6 in) • Height: 21.08 m (69 ft 2 in) • Wing area: 628 m^2 (6,760 sq ft) • Aspect ratio: 8.6 • Empty weight: 181,000 kg (399,037 lb) • Gross weight: 214,000 kg (471,789 lb) maximum fuel weight • Max takeoff weight: 402,000 kg	• Cruise speed: 865 km/h (537 mph, 467 kn) max 800–850 km/h (500–530 mph; 430–460 kn) at FL 328-394 (32,800–39,400 ft (9,997–12,009 m) at regional pressure setting) • Approach speed: 230–260 km/h (140–160 mph; 120–140 kn) • Range: 3,700 km (2,300 mi, 2,000 nmi) with max payload 8,400 km (5,200 mi; 4,500 nmi) with 80,000 kg (176,370 lb) payload 11,500 km (7,100 mi; 6,200 nmi) with 40,000 kg (88,185 lb) payload • Ferry range: 14,000 km (8,700 mi, 7,600 nmi) with max fuel and minimum payload • Service ceiling: 12,000 m

(886,258 lb) • Maximum landing weight: 330,000 kg (727,525 lb) • Fuel capacity: 348,740 l (92,130 US gal; 76,710 imp gal) • Powerplant: 4 × Progress D-18T high-bypass turbofan engines, 229 Kn (51,000 lbf) thrust each	(39,000 ft) max certified altitude • Take-off run (maximum take-off weight): 3,000 m (9,800 ft) • Landing roll (maximum landing weight): 900 m (3,000 ft)

Table 4

In table 4, they are represented the main characteristics of the Antonov An-124 Ruslan, as they are presented in the original Flight Manual of the aircraft.

3. A proposal for a multi-criteria analysis of military transport aircraft

This chapter is created in order to represent step by step the multi-criteria analysis I realised with the goal to make it understandable and easy to follow as a model for everyone who wants to create a multi-criteria analysis for any purpose.

3.1 Setting criteria for analysis and their weighting

I have established the most important 6 transport aircraft criteria, taking into account the information I found, as follows: RAG=range, CPY=capacity, CSP=cruise speed, MXS=maximum speed, CLG=ceiling, LNG=length. According to the multi-criteria analysis, I have established the weight of criterions, see Table 5. The evaluation of each criterion was finished with points from 0-10, taking into account the proportionality of the technical data for each transport aircraft.

$$\gamma_i = \frac{p + \Delta p + m + 0{,}5}{-\Delta p' + \frac{N_{crt}}{2}}$$

	RAG	**CPY**	**CSP**	**MXS**	**CLG**	**LNG**	Points	Level	Ratio
RAG	0.5	1	0	1	0	1	3.50	2.5	2.50
CPY	0	0.5	1	1	1	1	4.50	1	4.67
CSP	1	0	0.5	0.5	0.5	0.5	3.00	3	1.78
MXS	0	0	0.5	0.5	0.5	1	2.50	4	1.20
CLG	1	0	0.5	0.5	0.5	1	3.50	2.5	2.25
LNG	0	0	0	0	0	0.5	0.50	5	0.14

Table 5

3.2 Assessment of the considered transport aircraft

In Table 6, it can be seen the assessment of each transport aircraft, based on the criterion specified in Table 5 and the mathematic formula presented above.

Solutions / criteria	**C-5 GALAXY**	**AIRBUS A400M**	**IL-76MD CANDID**	**AN-124**
Criterion	N_i	N_i	N_i	N_i
RAG	7.7	5.1	5.7	7.7
CPY	6.8	7.2	7.6	9.6
CSP	4.6	10	8.7	10
MXS	5.4	5.8	6.2	6.3
CLG	5.1	4.7	7.4	5.4
LNG	5.1	6.3	6.6	6

Table 6

The resulted assessment helps in order to create the consequence matrix, and the final step of the multi-criteria analysis, as it follows.

3.3 Hierarchy according to the consequence matrix

Considering the score taken on each transport aircraft, a matrix of consequences has been resulted, see Table 7, culminating in a final classification.

Solutions / criteria	**C-5 GALAXY**	**AIRBUS A400M**	**IL-76MD CANDID**	**AN-124**
Criterion	$N_i \, x \, \gamma_i$	$N_i \, x \, \gamma_i$	$N_i \, x \, \gamma_i$	$Ni \, x \, \gamma i$
RAG	19.25	12.75	14.25	19.25
CPY	31.73	33.60	35.47	44.80
CSP	8.18	17.78	15.47	17.78
MXS	6.48	6.96	7.44	7.56
CLG	11.48	10.58	16.65	12.15
LNG	0.73	0.90	0.94	0.86
Final Ranking	**77.84**	**82.56**	**90.22**	**102.39**

Table 7

The steps of the multi-criteria analysis are essential to understand in order to create a objective and accurate conclusion, based on the consequence matrix.

4. Conclusions

Methods used in the evaluation of the transport aircraft provide a comprehensive image of their characteristics and performance, both in quantitative and qualitative terms, when choosing the ideal number of criteria considered both appropriately punctuated and representative. The multi-criteria analysis can be used to determine the best quality-price

relation, in order to obtain the optimal acquisition option for the modernization of the Armed Forces. These analyses are used in any procurement program for Air Force equipment, and they are relevant in order that it can be seen objectively which proposed variant is the most qualitative.

Beyond claiming a multi-criteria judgment at the highest level of confidence, I have set a hierarchy based on the 6 criteria chosen: range, capacity, cruise speed, maximum speed, ceiling, length.

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