POLITEHNICA" UNIVERSITY OF BUCHAREST

DOCTORAL SCHOOL OF AEROSPACE ENGINEERING

PHD THESIS SUMMARY

Study on the extension of maintenance activities in theaters of operations for the C130 Hercules aircraft

Author: Marius-Alexandru VOICU

Scientific coordinator: Gl.fl.aer.(r) prof. univ. dr. ing. Ion FUIOREA

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CONTENTS OF THE DOCTORAL THESIS

KEY WORDS: maintenance, reliability, turboprop aircraft, medium curier, corrective maintenance, analysis, failure, critical parts, weight, endurance, range, flight performance.

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INTRODUCTION AND OBJECTIVES OF THE THESIS

Modern maintenance contributes to sustainable development in society, including measures related to environmental protection, reduction of energy consumption and economic and safety issues. The advanced level of execution of maintenance activities has an essential role in increasing competitiveness, the technology not being efficient without excellent management. Reliability, availability and planning are key factors in competitiveness, which have been advanced for the first time in the nuclear energy industry, being quickly followed by the aerospace industry.

Maintenance aims to ensure the operation of technical systems and equipment. This is done with adequate measures through which a technical work system / equipment is maintained functionally through measures that preserve or restore its working parameters in conditions of increasing quality demands. Each time a system fails, it is necessary to follow a series of steps to repair it or restore it to its full operability. These steps include: diagnosing the defect, isolating it, disassembling the equipment to gain access to the defective part, and repairing it.

In order to meet the requirements of the system, the normal tendency is to address primarily those elements of equipment that have direct implications for mission performance, such as primary equipment, operating personnel, software, and associated data. At the same time, very little attention is paid to the maintenance and logistical support of the system.

In order to meet the general objectives of systems engineering, it is essential that all aspects involving the operation of the system are considered on an integrated basis. This includes not only segments geared towards the execution of the mission itself but also logistical support capacity. This needs to be taken into account from the outset (during the feasibility analysis when evaluating new technologies for possible application) and an initial maintenance concept needs to be developed, on how the proposed system is to be designed and operated.

However, existing methods are not always easy to apply, where availability is often a more important criterion than reliability, in other words, downtime is more important than a low probability of failure. An error is acceptable if repair and restart times are short, so maintaining the system and ensuring a successful maintenance process is the key to mission success in most cases.

The research target is the analysis of the complexity of maintenance activities performed in theaters of international military operations, for C-130 Hercules aircraft within the Romanian Air Force, to fulfill the full range of missions in which they are engaged, effectively using modern research methods. To this end, we have drawn up the parts warehouse, which we have called the minimum operational stock with which the aircraft should go on air transport missions to theaters of operations so that their success rate is maximum. Afterwards, the way in which the flight performance calculations were performed will be presented, in order to find out the influence of the additional weight generated by the parts warehouse and to prove the effectiveness of these measures.

CHAPTER 1. CURRENT STATE OF MAINTENANCE ACTIVITIES IN THEATER OF OPERATIONS FOR C-130 HERCULES TRANSPORT AIRCRAFT

The logistical support of the air component is a decisive factor in fulfilling its missions in independent or joint operations and is exercised through the functional areas of logistics.

Ensuring the technical availability of equipment, necessary for conducting air operations, highlights the fact that the use of air forces depends to a very large extent on maintenance.

As with any technical system, the C-130 Hercules aircraft undergoes preventive, corrective and complex maintenance activities, which are a combination of the first two, applied according to the functional criteria specific to the use of the systems.

Depending on the complexity of maintenance activities, it can be classified into:

- maintenance at the basic level (A) - operational - is performed at the maintenance teams intended to prepare the flight from the aviation aviation organization, by the technical crew of the aircraft and the technical maintenance teams, with short-term immobilization of aviation equipment and involves visual inspection of the integrity of the aircraft and whether there are liquid leaks from the installations. This includes:
- daily inspections, which are performed before the first flight of the day;
- capacity restoration (performed between consecutive flights);
- post-flight inspections.

- maintenance at intermediate level (B) - is performed at the aircraft maintenance section of the aeronautical organization, involves the immobilization of aviation equipment over a medium period of time and involves operations such as:
- periodic inspections performed on aircraft systems, according to inspection cards;
- ordered inspections of hierarchically superior maintenance structures;
- tests / diagnoses, adjustments, calibrations, alignments of modules and system components;
- repairs and replacements of modules / components;
- fuselage repairs;
- repairs of radio and electronic equipment;
- preparation and evacuation of aircraft that are not repaired at this level, to economic agents.

- complex level maintenance (C) - involves the immobilization of aircraft for a relatively long time and is performed at the complex works section of the aeronautical organization or repair agents who are authorized to perform major repairs, overhauls, modifications, upgrades.

Maintenance in international activities of C-130 Hercules transport aircraft, which have crew members on board, may also be performed with their participation. During international missions, on-call and deployment aerodromes, maintenance activities shall be carried out comprising:

- between missions check;
- restoration of flight capacity;
- after flight check;
- refilling with fuels, lubricants, special liquids and compressed gases;
- analysis and interpretation of data provided by flight parameter recording systems;
- loading flight parameter recording systems;
- supplying on-board systems with the materials necessary to fulfill the flight mission;
- repairing reported failures by crew members and those found during the inspection.

CHAPTER 2. METHODS OF MAINTENANCE ANALYSIS FOR C-130 HERCULES TRANSPORT AIRCRAFT

The purpose of the second chapter is to establish the critical components of the aircraft, those with the highest failure rate in order to be able to prepare the minimum operational spare parts stock with which it will depart on air transport flights so that the probability of fulfilling the missions to be maximum.

For the case study, in the first subchapter, was made a situation with the defects occurred operating two C-130 Hercules aircraft by the Romanian Air Force, generically named, aircraft A and aircraft B, between January 2018 and December 2019 .

As a result of the centralized situation, was obtained a total number of 308 defects, of which 170 for aircraft A and 138 for aircraft B.

During the study it was found that most of the defects were noticed by the pilots during the flight, namely 190, of which 94 on aircraft A and 96 on B, while on the ground, the technical team of the aircraft found 118, 76 at aircraft A and 42 to B.

Regarding the cause of the defects, it was found that the main cause is the failure of the material, resulting in a number of 235 defects out of a total of 308.

In second place were identified 21 system malfunctions, found mainly in the fuel correction and control system (TD), the negative torque detection system (NTS), but also in auxiliary equipment installed on the aircraft (lighting systems , door locks, etc.);

- 15 defects caused by open circuits / imperfect contacts were discovered on the measuring and control devices on board the aircraft, on radio stations and on electronic engine control systems;
- 15 defects were due to clogging of filters or systems;
- 10 situations of pressure loss due to loss of tightness in the case of shock absorbers on the landing gear, parts of the entire hydraulic installation, or the parking brake;
- 3 decalibration situations caused defects in the fuel gauges and radio stations;
- 9 situations in which the deposits of impurities caused defects in the brake blocks, the air conditioning system and in the transmitter of the quantity of oil from the engine.

In the second subchapter, was calculated the mean corrective maintenance time for the C-130 Hercules aircraft, based on the fault situation. The corrective maintenance cycles times for each failure, were noted in the two tables below.

Table 2.1 Corrective maintenance times aircraft A

Aeronava A	Timpi reparații (min)																							
	Celulă					Motor						Instalații speciale										Radio		
Ian-18	132	217	-	-	-	95	47	191	-	-	-	114	93	-	-	-	-		-	-	-	155	-	-
Feb-18	115	-	-	-	-	-	-	-	-	-	-	73	201	194	191	242	115	84	168	257	186	-	-	-
Mar-18	215	124	290	-	-	465	84	518	305	-	-	197	181	211	-	-	-	-	-	-	-	-	-	-
Apr-18	193	221	170	225	-	55	188	286	-	-	-	79	115	107	205	97	-	-	-	-	-	-	-	-
Mai-18	122	-	-	-	-	129	303	214	-	-	-	104	185	201	201	211	-	-	-	-	-	319	-	-
Iun-18	205	63	76	-	-	121	317	86	119	87	472	168	218	29	-	-	-	-	-	-	-	135	-	-
Iul-18	55	129	-	-	-	238	-	-	-	-	-	125	24	49	104	129	88	-	-	-	-	-	-	-
Aug-18	84	149	121	-	-	65	87	287	179	241	-	129	157	162	93	189	143	174	-	-	-	-	-	-
Sep-18	-	-	-	-	-	-	-	-	-	-	-	124	-	-	-	-	-	-	-	-	-	317	-	-
Oct-18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Noi-18	24	-	-	-	-	161	-	-	-	-	-	94	307	-	-	-	-	-	-	-	-	243	-	-
Dec-18	179	94	-	-	-	275	153	-	-	-	-	141	129	-	-	-	-	-	-	-	-	179	-	-
Ian-19	92	147	-	-	-	-	-	-	-	-	-	213	51	49	-	-	-	-	-	-	-	-	-	-
Feb-19	-	-	-	-	-	138	315	-	-	-	-	129	59	112	97	105	-	-	-	-	-	-	-	-
Mar-19	124	-	-	-	-	186	190	257	-	-	-	113	158	98	75	132	95	87	-	-	-	104	-	-
Apr-19	283	124	-	-	-	127	-	-	-	-	-	67	115	148	139	-	-	-	-	-	-	95	-	-
Mai-19	107	249	148	-	-	94	-	-	-	-	-	105	-	-	-	-	-	-	-	-	-	107	-	-
Iun-19	21	-	-	-	-	82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iul-19	187	97	118	205	158	208	153	243	-	-	-	57	213	-	-	-	-	-	-	-	-	121	39	89
Aug-19	241	205	-	-	-	138	117	125	175	-	-	-	-	-	-	-	-	-	-	-	-	43	118	-
Sep-19	-	-	-	-	-	287	56	136	197	-	-	99	-	-	-	-	-	-	-	-	-	-	-	-
Oct-19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Noi-19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2.2 Corrective maintenance times aircraft B

Aeronava B	Timpi reparații (min)																							
	Celulă					Motor						Instalații speciale										Radio		
Ian-18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-
Feb-18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mar-18	215	259	-	-	-	281	119	123	-	-	-	136	240	127	87	58	62	175	-	-	-	105	145	139
Apr-18	-	-	-	-	-	166	-	-	-	-	-	195	124	-	-	-	-	-	-	-	-	-	-	-
Mai-18	84	92	227	115	-	154	-	-	-	-	-	146	162	-	-	-	-	-	-	-	-	122	-	-
Iun-18	65	311	-	-	-	491	-	-	-	-	-	94	-	-	-	-	-	-	-	-	-	-	-	-
Iul-18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug-18	81	-	-	-	-	304	-	-	-	-	-	133	-	-	-	-	-	-	-	-	-	97	-	-
Sep-18	212	-	-	-	-	95	128	-	-	-	-	195	107	124	45	309	156	-	-	-	-	201	245	-
Oct-18	198	-	-	-	-	207	126	204	-	-	-	172	-	-	-	-	-	-	-	-	-	-	-	-
Noi-18	163	192	-	-	-	278	-	-	-	-	-	177	-	-	-	-	-	-	-	-	-	132	198	-
Dec-18	234	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	-	-
Ian-19	185	221	-	-	-	-	-	-	-	-	-	192	-	-	-	-	-	-	-	-	-	-	-	-
Feb-19	-	-	-	-	-	84	382	-	-	-	-	62	-	-	-	-	-	-	-	-	-	91	-	-
Mar-19	-	-	-	-	-	283	195	317	-	-	-	139	-	-	-	-	-	-	-	-	-	-	-	-
Apr-19	-	-	-	-	-	584	376	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mai-19	-	-	-	-	-	209	146	153	-	-	-	174	-	-	-	-	-	-	-	-	-	-	-	-
Iun-19	556	124	311	39	-	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	86	-	-
Iul-19	207	-	-	-	-	177	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug-19	61	65	-	-	-	-	-	-	-	-	-	303	80	-	-	-	-	-	-	-	-	96	-	-
Sep-19	208	-	-	-	-	84	-	-	-	-	-	117	96	-	-	-	-	-	-	-	-	-	-	-
Oct-19	-	-	-	-	-	248	195	169	108	-	-	139	218	173	74	139	-	-	-	-	-	-	-	-
Noi-19	207	-	-	-	-	219	119	-	-	-	-	87	192	-	-	-	-	-	-	-	-	161	-	-

A total of 275 complete maintenance cycles were identified and the mean corrective maintenance time is 162 minutes.

The obtained times were entered in a single table, in order to then make the frequency table and the frequency histogram.

Table 2.3 – Corrective maintenance times

132	217	95	47	191	114	93	155	115	73	201	194	191	242	115	84	168	257	186	215	124	290	465	84	518
305	197	181	211	193	221	170	225	55	188	286	79	115	107	205	97	122	129	303	214	104	185	201	201	211
319	205	63	76	121	317	86	119	87	472	168	218	29	135	55	129	238	125	24	49	104	129	88	84	149
121	65	87	287	179	241	129	157	162	93	189	143	174	124	317	24	161	94	307	243	179	94	275	153	141
129	179	92	147	138	315	213	51	49	129	59	112	97	105	124	186	190	257	113	158	98	75	132	95	87
104	283	124	127	67	115	148	139	95	107	249	148	94	105	107	21	82	187	97	118	205	158	208	153	243
57	213	121	39	89	241	205	138	117	125	175	43	118	287	56	136	197	99	215	259	281	119	123	136	240
127	87	58	62	175	105	145	139	166	195	124	84	92	227	115	154	146	162	122	65	311	491	94	81	304
133	97	212	95	128	195	107	124	45	309	156	201	245	198	207	126	204	172	163	192	278	177	132	198	234
29	185	221	84	382	192	62	91	283	195	317	139	584	376	209	146	153	174	86	556	124	311	39	47	207
177	61	65	303	80	96	208	84	117	96	248	195	169	108	139	218	173	74	139	207	219	119	87	192	161

For this, the repair times were conveniently divided into classes of 30 minutes each, and the separation points between classes will be 30.5, 60.5, 90.5, thus obtaining the histogram of maintenance actions.

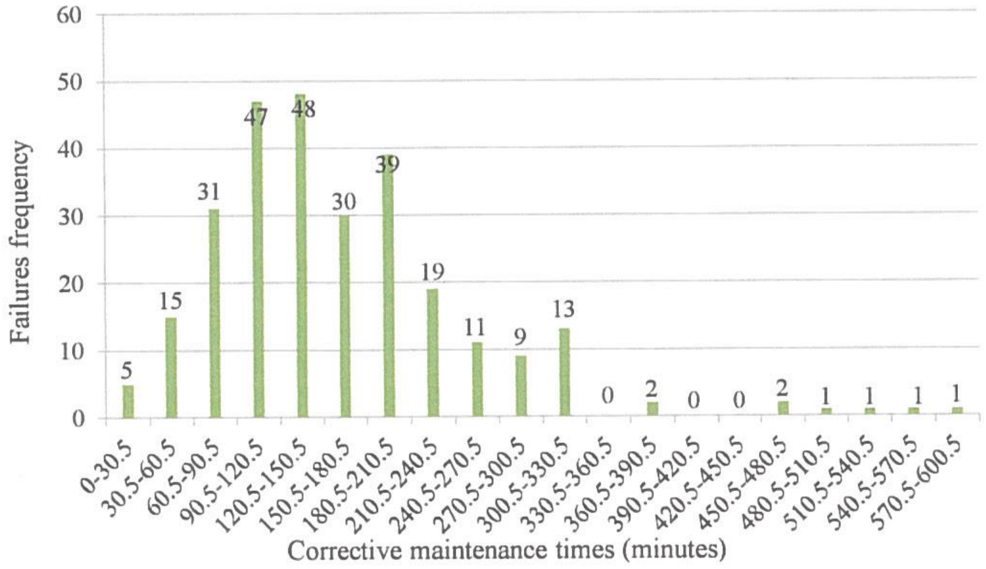

Fig. 2.1 Maintenance actions histogram

As can be seen from the representation of the frequency polygon, the repair time and frequency vary, resulting in it is corresponding to the continuous probability distribution ("log-normal distribution").

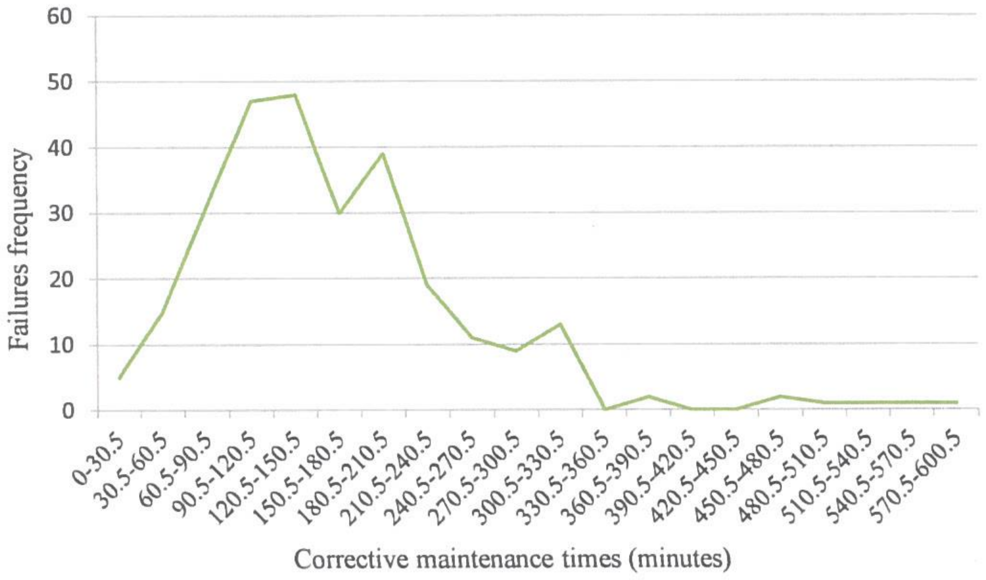

Fig 2.2 Frequency poligon

The next subchapter presents the mean time between failure (MTBF). To exemplify the calculation of it, some of the defects occurred in the studied interval were listed:

a) 12 defects in the oil radiator flap, 8 of them appeared during the flight, and 4 were detected and repaired by the aircraft maintenance service, on the ground.

- The failure rate is 4.8 defects per thousand hours;
- The average time between failures is 208.33 hours;
- Reliability is 0.89.

b) 11 radio altimeter failures, of which 10 were reported by the pilots after the flight, and one identified on the ground by the technical staff.

- The failure rate is 4.4 defects per thousand hours;
- The average operating time between failures is 227.27 hours;
- The reliability of the radio altimeter is 0.90.

c) 10 failures at the brake system, either discovered by the technical team or reported by the pilots after the flight, all occurred on the ground.

- The failure rate is 4 defects per thousand hours;
- The average operating time between failures is 250 hours;
- The reliability is 0.91.

d) 12 engine speed indication defects.

- There were 4 different causes;
- The reliability of the components was higher than 0.90.

e) 7 generator defects, 4 were discovered and remedied by the aircraft maintenance service, and 3 occurred during the flight

- The failure rate is 2.8 defects per thousand hours;
- The average operating time between failures is 357.10 hours;
- The reliability of the generator is 0.94.

Application of simplified analysis of failure mode and effects

The failure analysis is with respect to the risk priority number, RPN, as part of FMEA, and RCM, respectively. For each mode of failure, a potential effect of the failure is anticipated as the gravity (or severity) that the failure could have in the system functioning objective (the mission for which it was designed). The associated index/ rank, G, and the significance of the failure gravity are proposed as presented in Table 2.4.

Gravity of the failure *Table 2.4*

G	Significance
1	Insignificant effect, corrected immediately by the technician.
2	Insignificant effect, corrected immediately by maintenance personnel.
3	Minor effect, the component element will suffer a gradual degradation if not intervened. The mission is not affected.
4	Moderate effect, mission may be affected. A repair may be required along the way.
5	Moderate effect. Surely repairs will be needed and the mission is partially damaged.
6	Moderate to high effect. A certain part of the mission cannot be accomplished. Delays in restoring function.
7	High effect. An important part of the mission cannot be accomplished. Significant delays in restoring function.
8	High effect. The mission cannot be accomplished. Significant delays in restoring function.
9	Effects on operational safety, consequences for crew health and the environment. The operation is stopped with the warning of the crew.
10	Effects on operational safety, consequences for crew health and the environment. The operation is stopped without warning the crew.

The next step is to evaluate the frequency of failure. In general, this indicator must be established for each fault mode taking into account the maintenance activity history for the last three years. The associated index/rank, F, reference value and the significance of the failure frequency are proposed as presented in Table 2.5.

Frequency of the failure *Table 2.5*

D	Reference atribute	Significance
1	1/10000	Very low failure rate. We should not expect the defect to occur.
2	1/5000	Low failure rate. The fault is unlikely to occur.
3	1/2000	Low failure rate, similar to that of products already checked.
4	1/1000	Moderate to low failure rate, previously checked.
5	1/500	Moderate failure rate, previously verified.
6	1/200	Moderate to high failure rate, previously verified.
7	1/100	High verified failure rate.
8	1/50	High failure rate. It can cause problems.
9	1/20	Very high failure rate. Problems will almost certainly arise.
10	1/10+	Very high failure rate. Surely problems will arise.

Detectability of failure is a parameter that considers the possibility of detecting the defect, if it occurred. The associated index/ rank, D, reference attribute and the significance of the failure detectability are proposed as presented in Table 2.6.

Detectability of the failure *Table 2.6*

D	Reference atribute	Significance
1	Almost sure	Automatically detected fault.
2	Very high	Most likely the fault is detected very quickly.
3	High	Most likely, known control operation will detect the fault.
4	Moderately high	There is a moderately high probability that known control operations will detect the fault.
5	Moderate	There is a moderate probability that known control operations will detect the fault.
6	Low	There is a low probability that known control operations will detect the fault.
7	Very low	There is a very low probability that known control operations will detect the fault.
8	Hard to detect	In some cases, known operations may detect the fault.
9	Improbable	Known control operations are unlikely to detect the fault.
10	Almost impossible	No control operations are known to detect the occurrence of the fault.

The effective failure data have to be registered, for example as presented in Table 2.7.

Table 2.7

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

where, in principle: 1 is the component name, 2 - failure date, 3 - failure discovery date, 4 - function, 5 - functional defect, 6 - failure identification method, 7 - failure causes, 8 - failure effects, 9 - G value, 10 - F value, 11 - D value, 12 - RPN value, 13 - improvements, 14 - new F value, 15 - new D value, 16 - new RPN value.

The risk priority number, RPN, is calculated as product of indices G, F, and D, i.e.

$$RPN = G \times F \times D \tag{1}$$

RPN is analyzed with the main purpose to optimize its value, by improving the preventive maintenance and the monitoring system. The necessary improvements will be made, as additional predictive maintenance that could, for example, detect misalignments, imbalances, etc. Frequency and detectability indices will be reevaluated, in order to obtain the new RPN.

The failure mode and effects simplified analysis results are referring to three evaluating criteria:

(1) The impact of the defect on the functioning capacity of the technical system;

(2) The probability that a specific mode of failure will occur, probability given by previous experience or existing statistics in the literature;

(3) The probability of detecting the defect before production, but with the means of maintenance that are available at that time.

Failures of aircraft structure components

Most structure components failures were detected during the preliminary flight preparation, as 26 out of 54 total cases. It is to remark that preventive maintenance and the monitoring system are highly efficient.

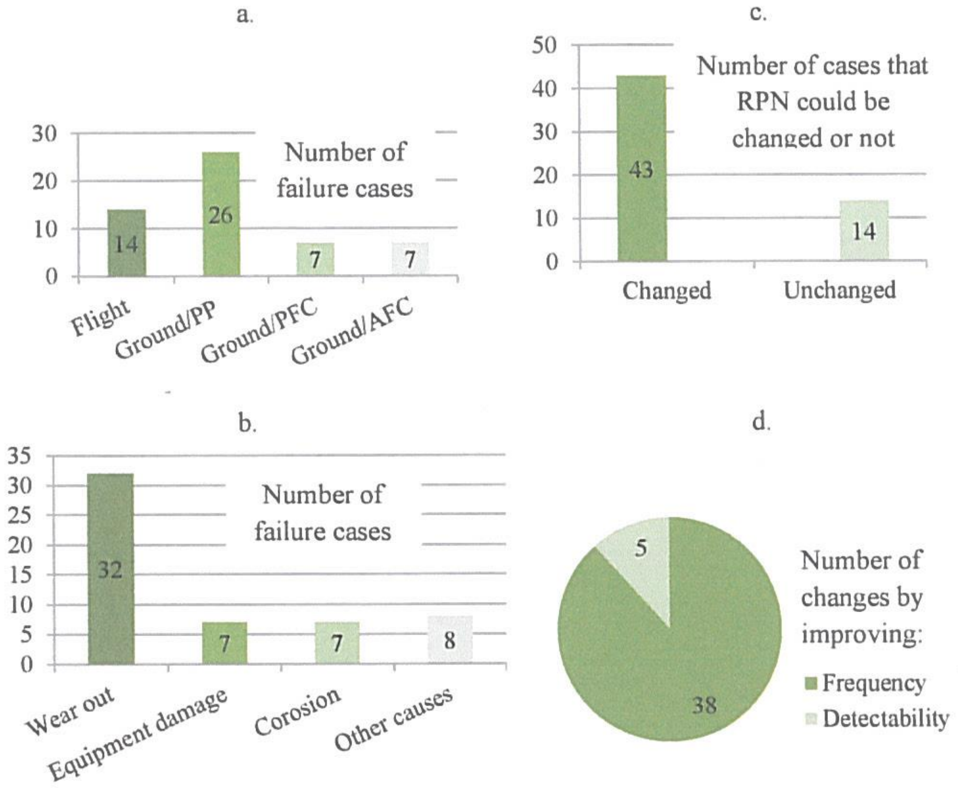

Fig. 2.3. Data associated to structure components failures – place/ type of preparation where these were discovered (a), causes (b), RPN changes (c), number of changes by improving the frequency or detectability (d)

The main cause of defects is the wear, as 32 out of 54 total cases, most likely due to their age and the vibrations that affect the cell and its aggregates. The RPN could be considerable modified, as 75%, mainly by decreasing the failure frequency, i.e., index F. Thus, it can be deduced that the detection methods have a high yield, but initial F is characterized by a high value; the critical situations can be reduced by identifying as accurately as possible the aggregates with a high risk of failure and replacing them with some with higher reliability, adapted to the operating conditions (temperature, vibration, corrosion, etc.). This entails additional maintenance costs, but it is justified by higher aircraft availability and increased operational safety.

Existing methods for monitoring the system are sufficient to detect faults before they occur, in most cases. In some cases, the defects are caused by the relatively low reliability of the parts, but this can increase and lead to a decrease in the frequency of defects, even involves additional costs.

Failures of aircraft engine components

The charts present that most of the failures occurred during the flight and were mainly caused by clogging of the injectors and filters (from the lubrication system, fuel and hydraulics), which leads to the conclusion that preventive maintenance and monitoring system in technical systems of the engine type it is not carried out at maximum efficiency. Another important factor is the wear of the components, a somewhat normal situation, due to their age and the stress to which they are subjected under to high vibrations and temperatures inside/outside the engine, which decisively affect them.

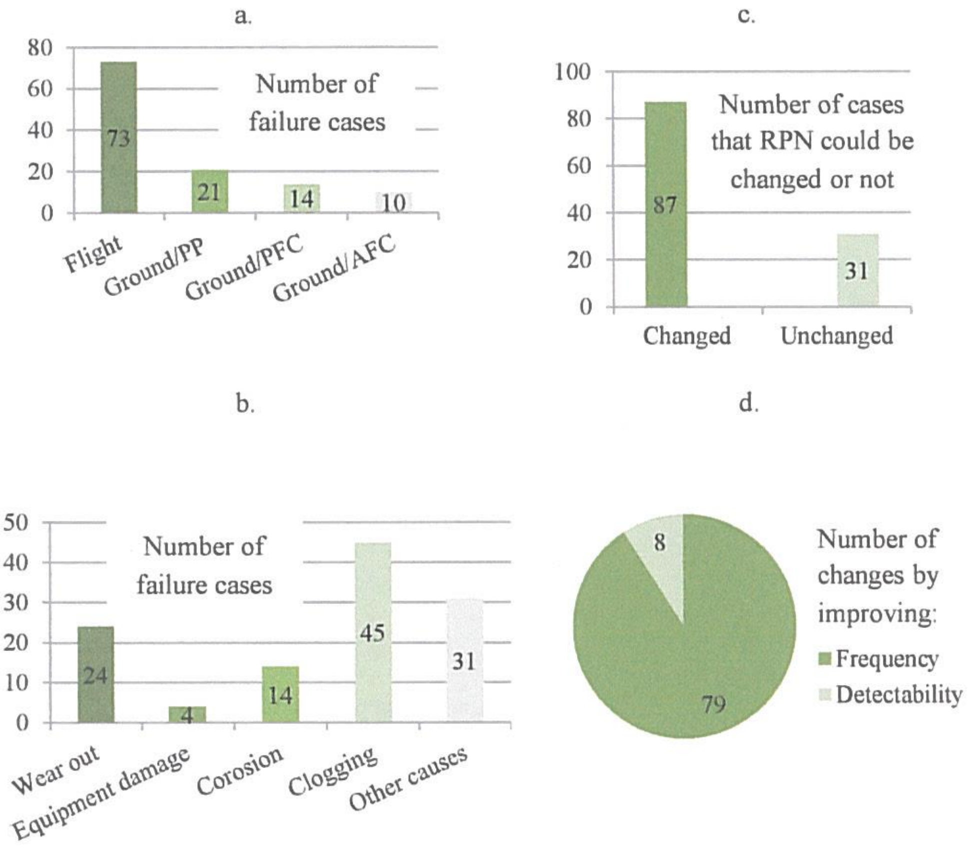

Fig. 2.4. Data associated to engine components failures – place/ type of preparation where these were discovered (a), causes (b), RPN changes (c), number of changes by improving the frequency or detectability (d)

It was possible to improve the RPN, in a large percentage, 74%. Like the analysis for structure technical systems, the engine-type systems involve the necessity to identify components with a high risk of failure and replace them with more reliable ones, adapted to operating conditions, with additional costs to ensure a proper maintenance.

It is necessary to streamline preventive procedures in order to reduce the probability of failure, by implementing predictive detection methods by using statistical detection methods and by compiling databases with defects found in the operation and highlighting the occurrence of new defects.

Failures of aircraft radio components

Among the causes underlying the occurrence of failures, it is observed that wear is by far the main reason, having the highest percentage compared to other specialties. Radio parts are sensitive to vibrations with high amplitudes and exposed for a long time (taking into account their age).

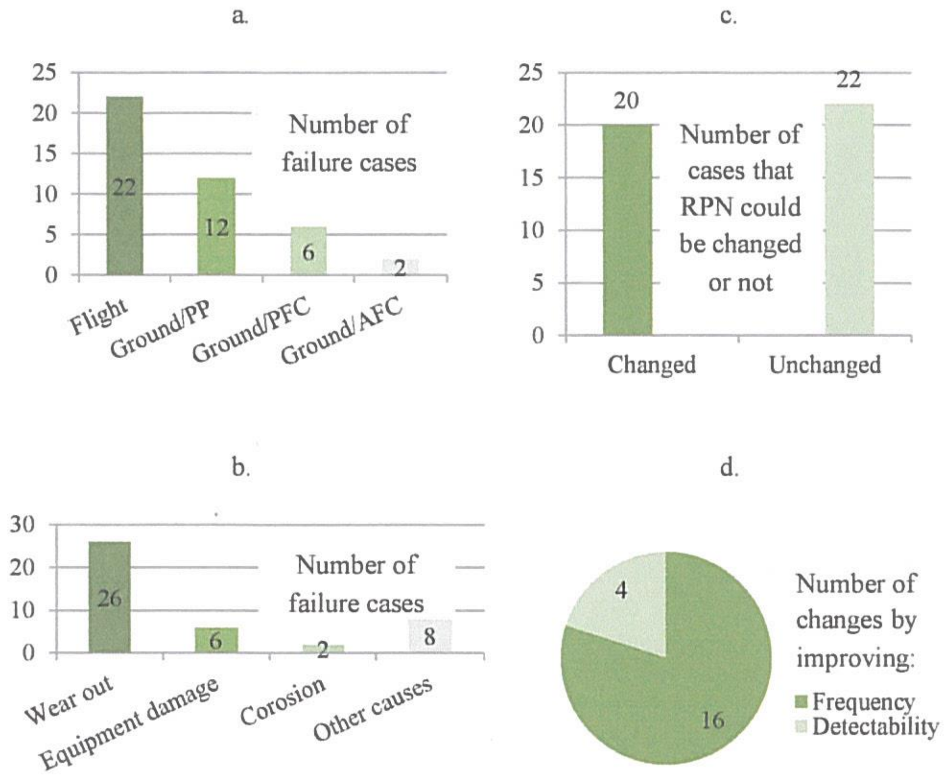

Fig. 2.5. Data associated to radio components failures – place/ type of preparation where these were discovered (a), causes (b), RPN changes (c), number of changes by improving the frequency or detectability (d)

The RPN could be changed in a lower percentage compared to other specialties, but the rule of improvement is maintained, optimizing it by reducing the frequency of failures in most situations. This can be influenced both by identifying the aggregates prone to damage, wear, corrosion, condensation, etc. as well as by replacing them with some with a high reliability, purchased directly from the manufacturer.

Detection methods can also be improved by specializing maintenance personnel in order to be able to identify in the structure of the aggregates, the components with lower reliability. It should be emphasized that the method entails additional maintenance costs, the adoption of which is dictated by the value of the investment.

Failures of aircraft special systems

According to the chart, most of the defects were identified during the flight (60%), a result which is the same as in the case of radio-type systems because some of the aggregates start only after take-off, for example the wing and empennage deicing installation. Almost a third of defects were detected during preliminary preparation and pre-flight inspection, indicating that preventive maintenance and the monitoring system have a good efficiency. It is therefore necessary to streamline preventive procedures in order to reduce the number of inflight failures.

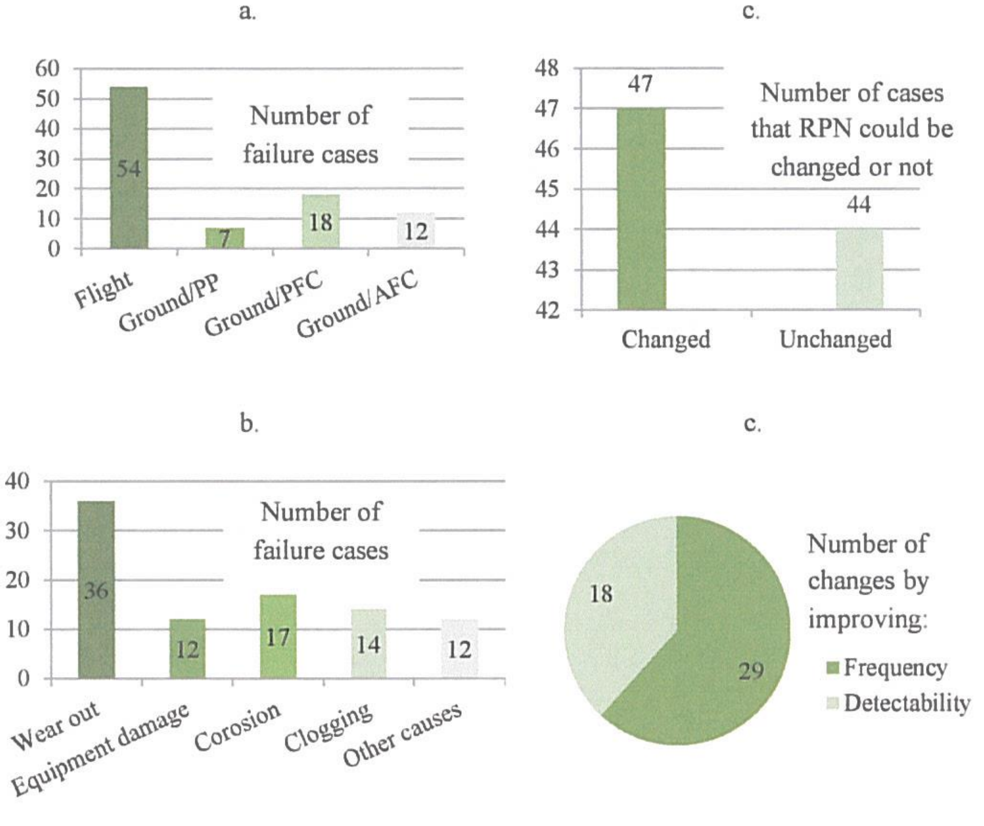

Fig. 2.6. Data associated to special systems failures – place/ type of preparation where these were discovered (a), causes (b), RPN changes (c), number of changes by improving the frequency or detectability (d)

The main factor leading to failures is again wear, especially due to the age of the aircraft and thus the aggregates.

The RPN could be improved, by reducing the frequency in the most of the cases, and proper measures can be imposed that can influence it both by identifying the aggregates prone to wear, corrosion, etc., and replacing them with more modern ones. and technically superior.

Applying FMEA analysis for the medium courier tourboprop aircrafts and studying the equipment technical documentation, the main causes of the failures and few ways to improve the system reliability could be noted.

RPN has been analyzed with the main purpose to optimize its value, by improving the preventive maintenance and the monitoring system. The necessary improvements were made, as additional predictive maintenance that could, by detecting misalignments, imbalances, frequency and detectability indices have been reevaluated, in order to obtain the new RPN.

Finally, existing preventive and corrective maintenance methods are sufficient to detect faults before they occur, in most of the situations. In some cases, the failures are caused by the relatively low reliability of the parts, but this can be increased and lead to a decrease in the frequency of defects, involving additional costs. FMEA analysis demonstrates again that it is a verified method of identifying equipment maintenance and support activities, performed in order to increase its availability by reducing the severity and frequency of failures. Although solving the technical problems encountered in performing the FMEA analysis is not easy, the main obstacles identified in implementing this strategy are related to the human factor and the management of the organization.

CHAPTER 3. MINIMUM OPERATIONAL SPARE PARTS STOCK AND PLANNING THE CRUISE FLIGHT FROM THE POINT OF VIEW OF THE ECONOMIC CONSIDERATIONS

Following the results of the methods of maintenance analysis carried out in the previous chapter, the parts with the highest frequency of failure and should be found in the stock with which the aircraft leaves for material and personnel transport missions to theaters of operations have been identified.

In addition, maintenance manuals and tools necessary for the operation of their replacement works will be included, which will be divided into crates so that the influence on the space, weight and balance of the aircraft will be minimal.

All the items weight 625.6 pounds, plus the weight of the crates in which they are stored (one metal and three wooden) obtaining a total weight of about 700 pounds. Given that the analysis refers to a military aircraft, the establishment of an integrated multinational logistical support system, similar to that used by civilian airlines, cannot be considered, so there is a need to bring on board the materials needed to ensure the fulfillment of missions at the highest parameters. The technical team needed to carry out the corrective maintenance work includes a number of four members, which leads to weight gain by about 800 pounds.

In conclusion, it is considered an extra weight of about 1500 pounds. Based on this, will be performed further performance calculations for the aircraft, in order to find out the influence on the two essential parameters in flight planning, endurance and autonomy.

In the calculation of the cruise flight the two factors, autonomy and endurance, refers the first to the maximum distance that can be traveled, and the second to the maximum time that the aircraft can spend in the air, both depending on the amount of fuel on board.

Endurance flight is the flight with a minimum fuel consumption for a given period of time. It is used in situations where the aircraft is required to spend more time in the air, such as waiting areas.

Maximum endurance is obtained at the speed at which fuel consumption is minimum for a certain configuration, altitude, temperature and weight. Optimal endurance is obtained at the speed and altitude that are obtained after the flight with a minimum fuel consumption for the given configuration, atmospheric conditions and weight.

As can be seen in the figure below, at high weights, the power required increases, resulting in increased consumption while reducing endurance.

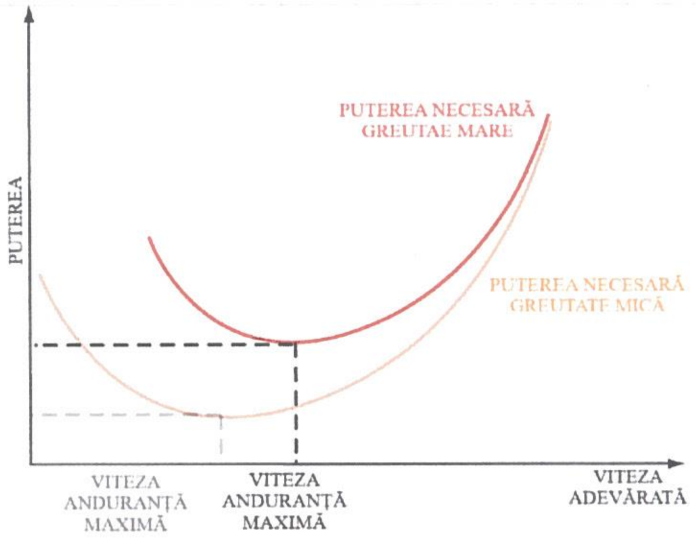

Fig. 3.1 Effect of weight on power required and speed for maximum endurance

While endurance refers to the time spent in the air, the autonomy focuses on the distance traveled by the aircraft. To improve autonomy, it is not enough to reduce consumption, but more importantly to increase the speed. Thus, the aircraft will cover a longer flight distance.

It is observed in figure 3.2 that for a higher weight, the necessary power increases, respectively the consumption, which leads to the decrease of the autonomy.

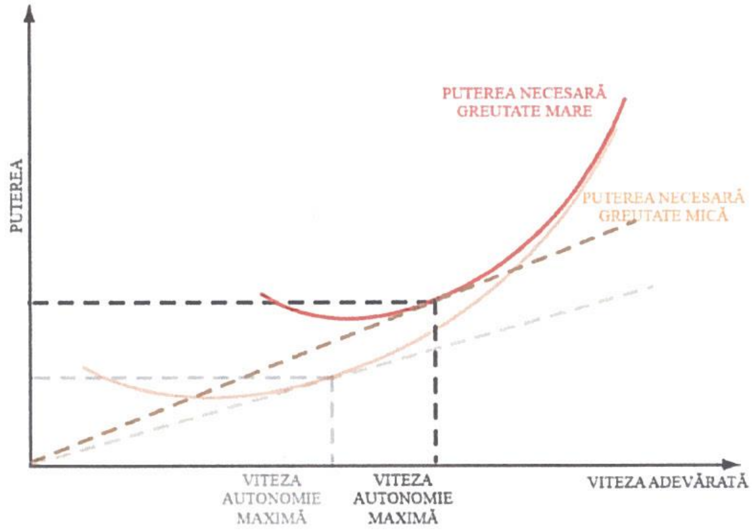

Fig. 3.2 Effect of weight on required power and speed specific to maximum range for a turboprop aircraft

Also, gaining weight leads to lowering the cruising ceiling, which implies increased fuel consumption. So we can see that an increased weight will reduce both endurance and range, so I will present some simulations to highlight the influence of the additional weight of 1500lbs, generated by bringing on board the minimum operational stock required to perform the mission in the theater of operations at maximum parameters.

1. Low altitude consumption with retracted train / flaps

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 140000 lbs	Weight 141500 lbs
ZFW = 107892 lbs	ZFW = 109392 lbs
Speed 230 knots	Speed 230 knots
Altitude 4000 feet	Altitude 4000 feet
Temperature - standard conditions	Temperature - standard conditions

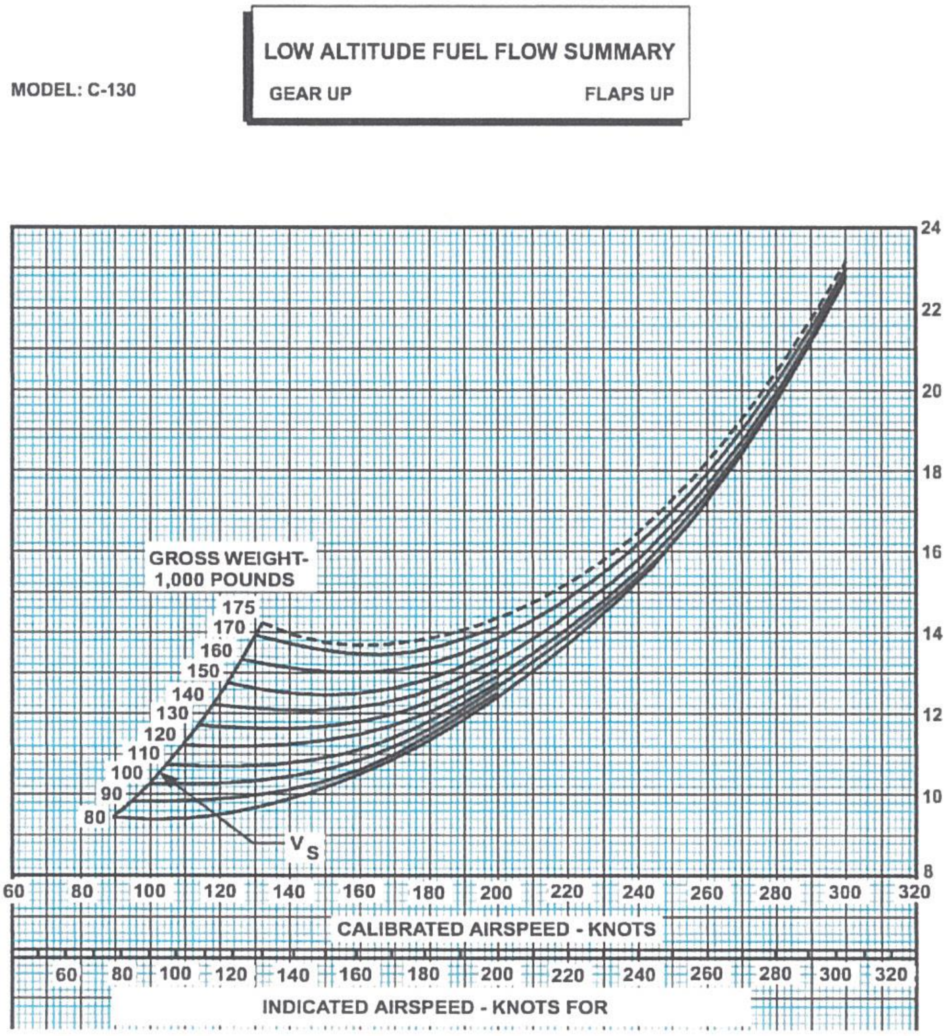

Fig. 3.3 Low altitude consumption with retracted train / flaps

As can be seen in the chart above, in the first situation, is obtained a consumption of approximately 1500 lbs/hour, which leads to a total consumption of 6000 lbs/hour.

In the case of the parts warehouse and the staff on board, hereinafter referred to as situation 2, is obtained a consumption of approximately 50 lbs/hour higher, which leads to a total consumption of 200 lbs/hour higher. There is an increase in consumption by 3.33%.

2. Low altitude consumption with retracted train, 50% flaps

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retractacted train - flaps 50%	Retractacted train - flaps 50%
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs	Weight 121500 lbs
ZFW = 87892 lbs	ZFW = 89392 lbs
Speed 170 knots	Speed 170 knots
Altitude 2500 feet	Altitude 2500 feet
Temperature - standard conditions	Temperature - standard conditions

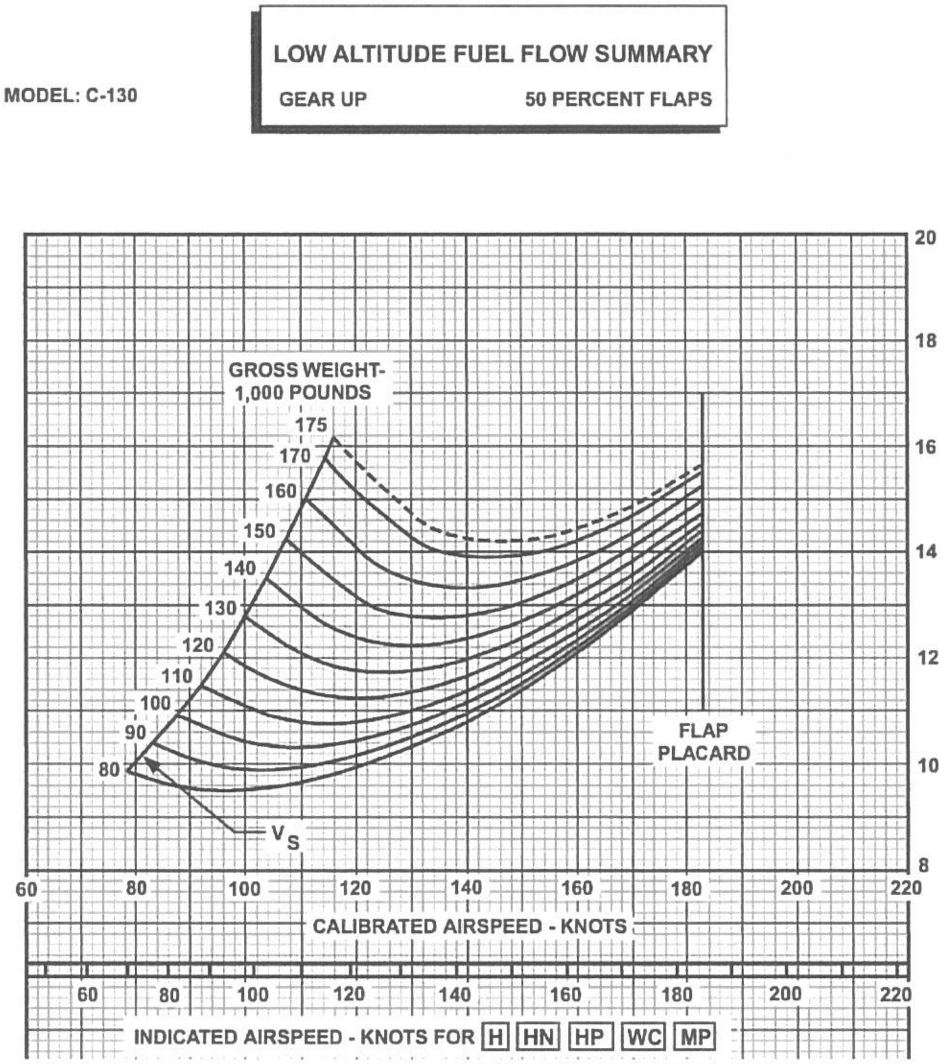

Fig. 3.4 Low altitude consumption with retracted train, flaps 50%

In first situation is obtained a consumption of 1260 lbs/hour per engine, which results in a total consumption of 5040 lbs/hour, while in situation 2, the consumption increases by 30 lb /hour per engine, which leads to a consumption total of 5160 lbs/hour. There is an increase in consumption by 2.38%.

3. Low altitude consumption with retracted train, flaps 100%

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retractacted train - flaps 100%	Retractacted train - flaps 100%
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs	Weight 121500 lbs
ZFW = 87892 lbs	ZFW=89392 lbs
Speed 140 knots	Speed 140 noduri
Altitude 1000 feet	Altitude 1000 feet
Temperature - standard conditions	Temperature - standard conditions

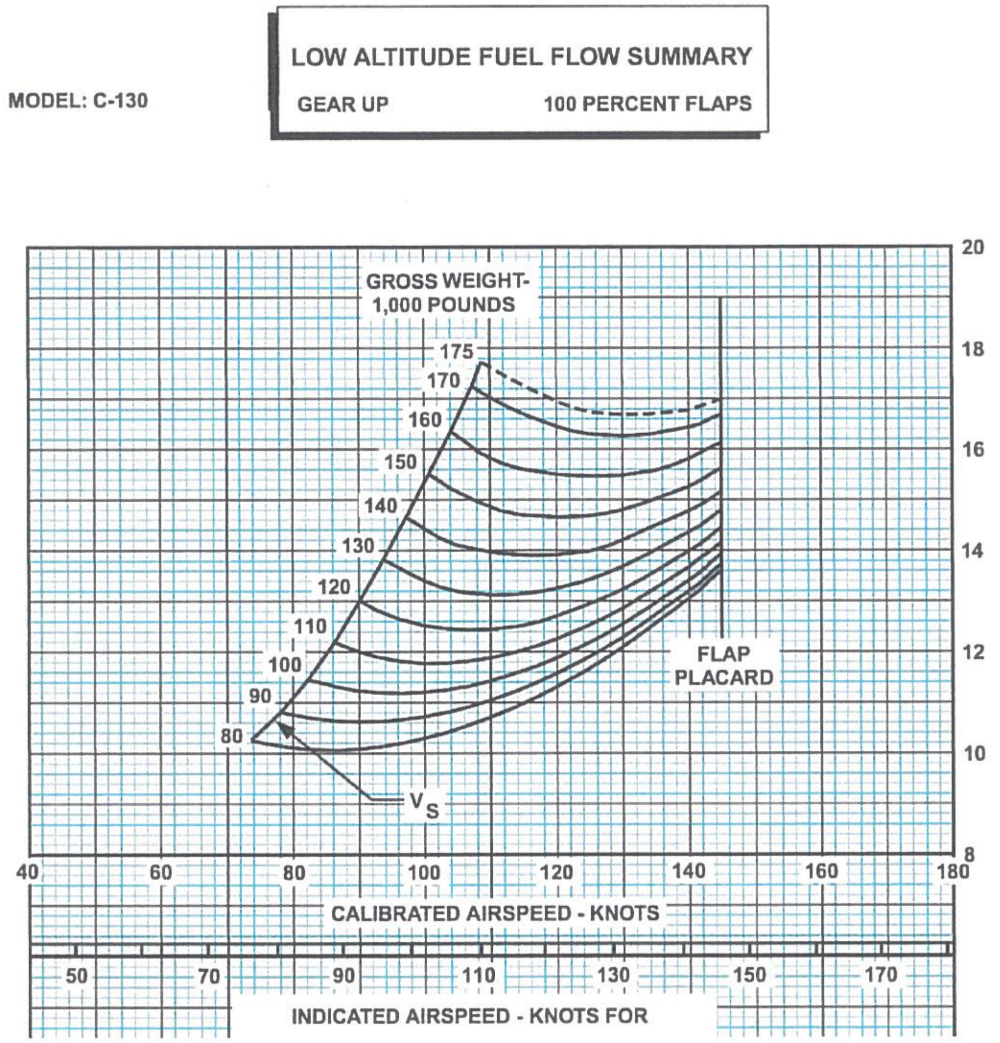

Fig.3.5. Low altitude consumption with retracted train, 100% flaps

In first situation is obtained a consumption of 1400 lbs/hour per engine, which results in a total consumption of 5600 lbs/hour, while in situation 2, the consumption increases by 60 lbs/hour per engine, which leads to a consumption total of 5840 lbs/hour. There is an increase in consumption by 4.28%.

4. Specific range at sea level

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs	Weight 121500 lbs
ZFW = 87892 lbs	ZFW=89392 lbs
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - sea level	Altitude - sea level
Temperature - standard conditions	Temperature - standard conditions

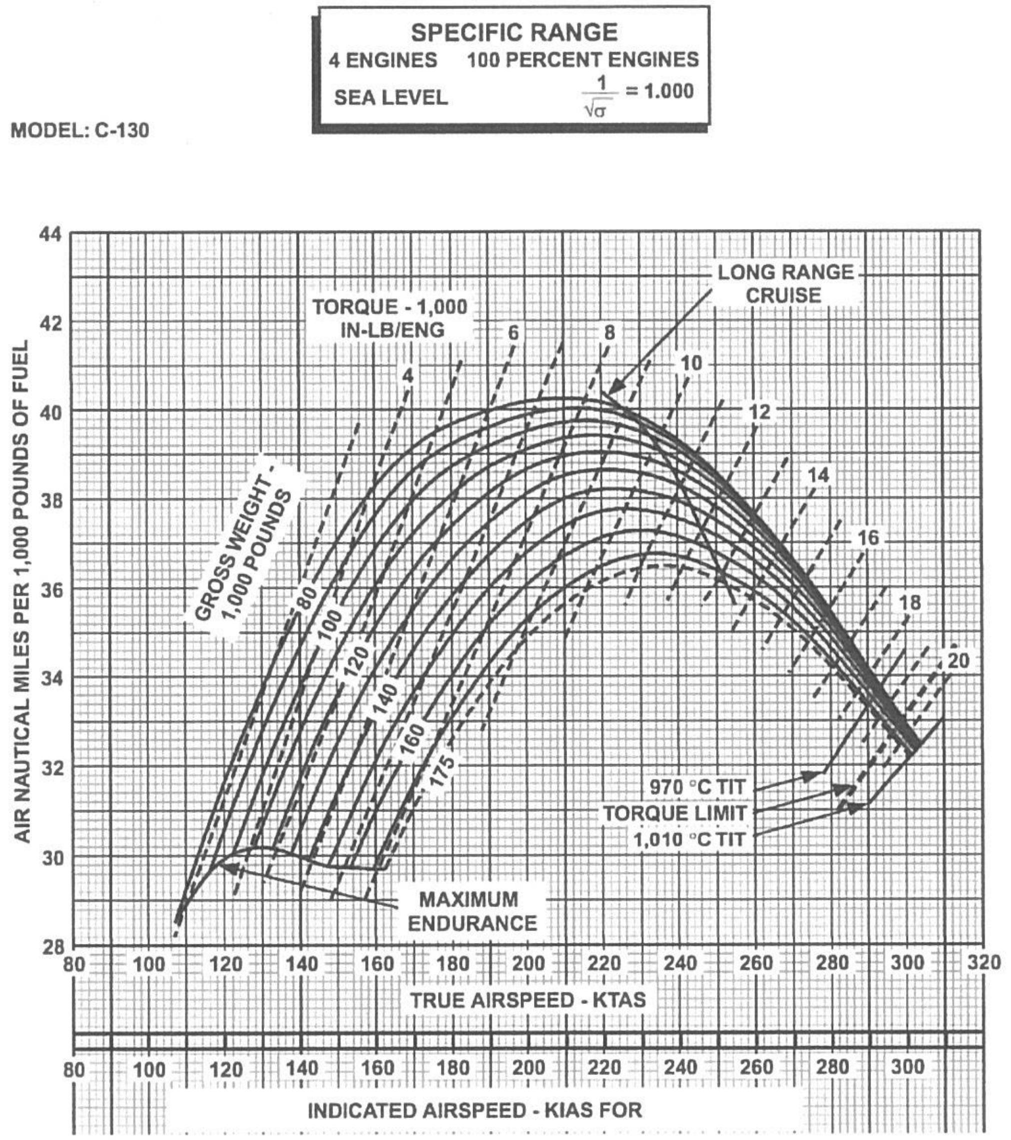

Fig. 3.6 Specific range at sea level

In first situation, range obtained is 37.4 nautical miles for 1000 lbs of fuel consumed, while in situation 2, it will be reduced with 1.21, becoming 36.19. There is a decrease in range by 3.23%.

5. Specific range at 5000FT

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs	Weight 121500 lbs
ZFW = 87892 lbs	ZFW=89392 lbs
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 5000FT	Altitude - 5000FT
Temperature - standard conditions	Temperature - standard conditions

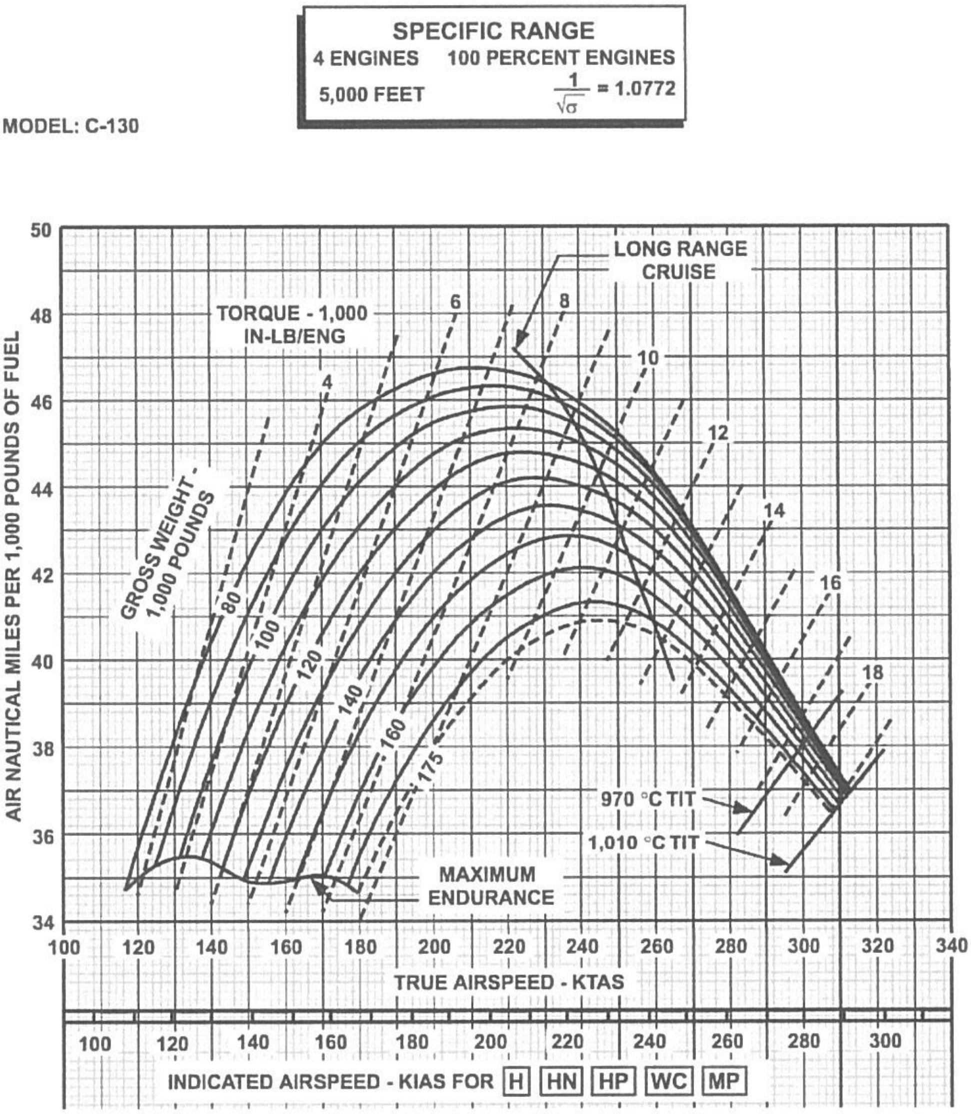

Fig. 3.7 Specific range at 5000FT

In first situation, range obtained is 43,4 nautical miles for 1000 lbs of fuel consumed, while in situation 2, it will be reduced with 1.51, becoming 41,89. There is a decrease in range by 3. 47%.

6. Specific range at 10000FT

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs	Weight 121500 lbs
ZFW = 87892 lbs	ZFW=89392 lbs
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 10000FT	Altitude - 10000FT
Temperature - standard conditions	Temperature - standard conditions

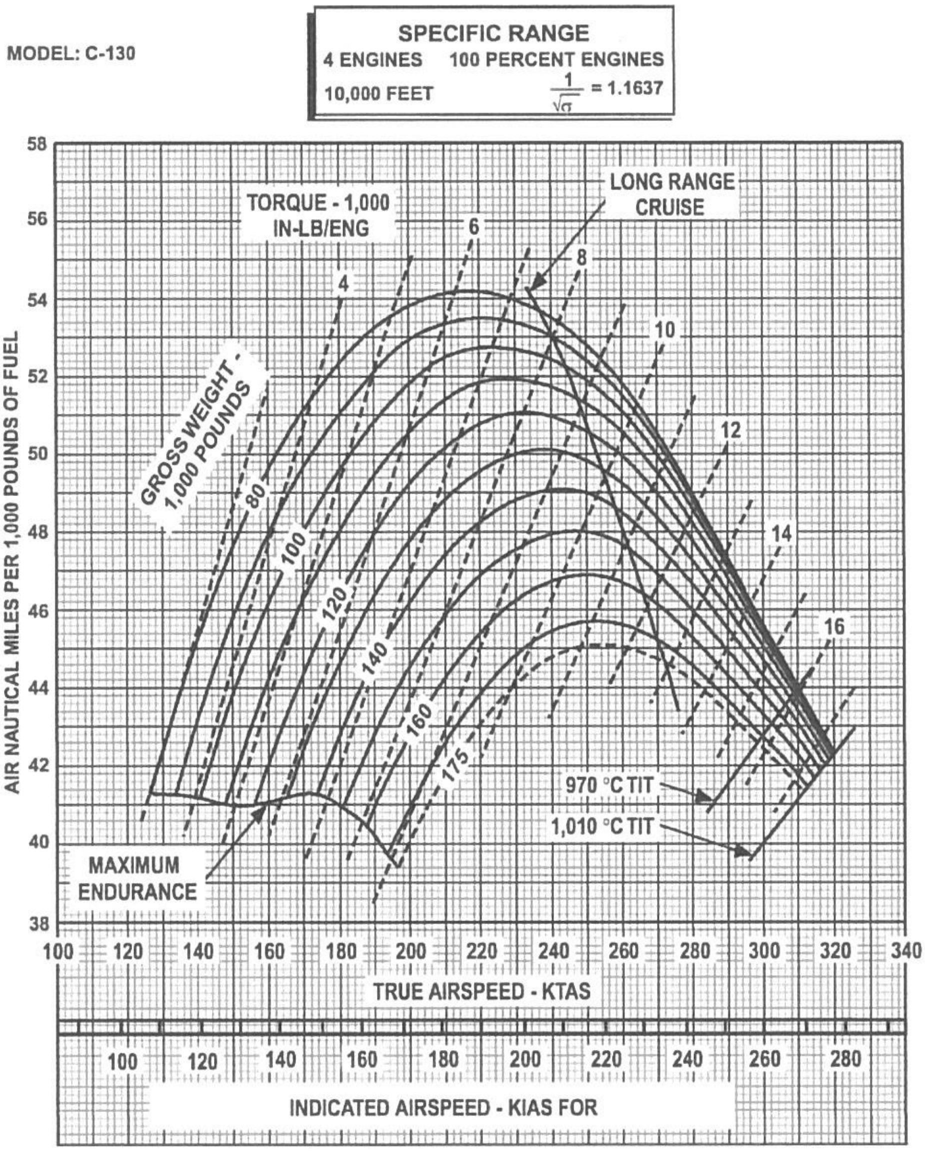

Fig.3.8 Specific range at 10000FT

In first situation, range obtained is 50 nautical miles for 1000 lbs of fuel consumed, while in situation 2, it will be reduced with 1.81, becoming 48,19. There is a decrease in range by 3,62 %.

7. Specific range at 15000FT

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs	Weight 121500 lbs
ZFW = 87892 lbs	ZFW=89392 lbs
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 15000FT	Altitude - 15000FT
Temperature - standard conditions	Temperature - standard conditions

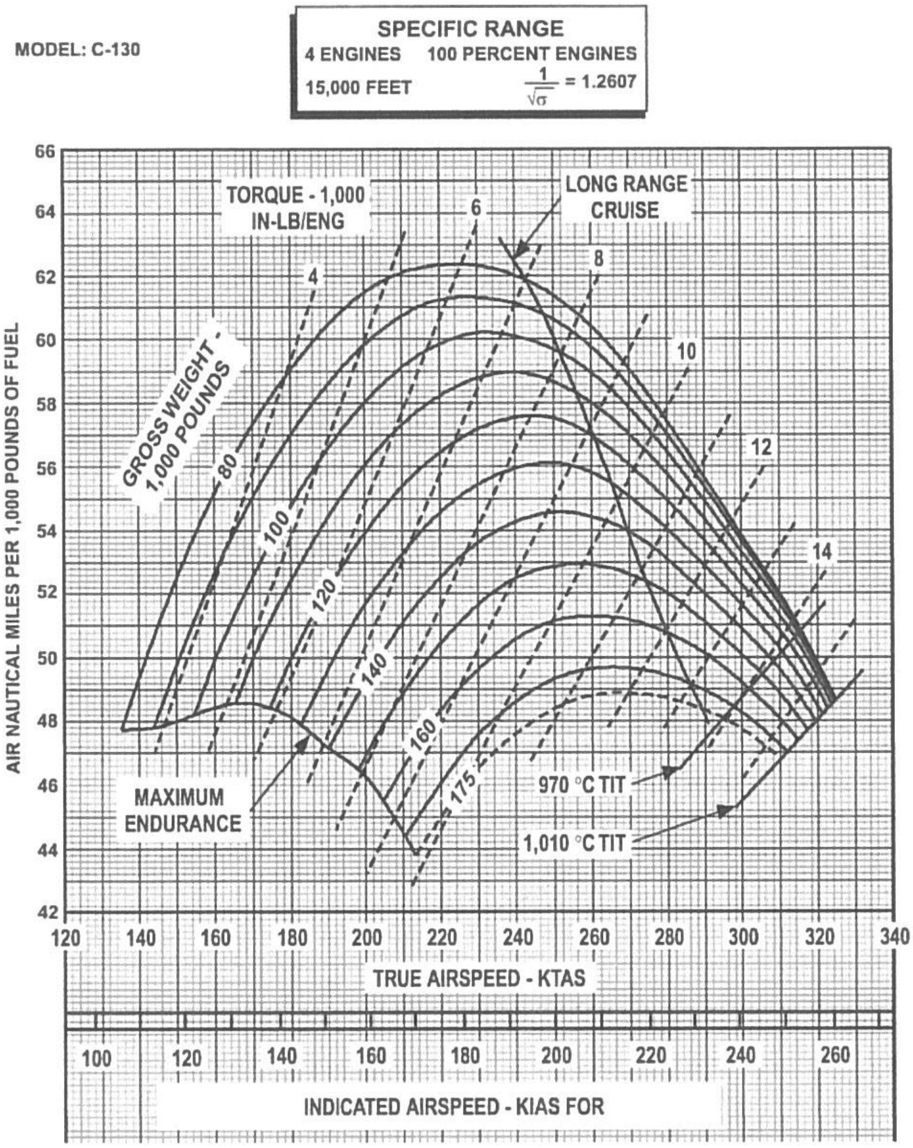

Fig. 3.9 Specific range at 15000FT

In first situation, range obtained is 56,9 nautical miles for 1000 lbs of fuel consumed, while in situation 2, it will be reduced with 2,42, becoming 54,48. There is a decrease in range by 4,25%.

8. Specific range at 20000FT

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs	Weight 121500 lbs
ZFW = 87892 lbs	ZFW=89392 lbs
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 20000FT	Altitude - 20000FT
Temperature - standard conditions	Temperature - standard conditions

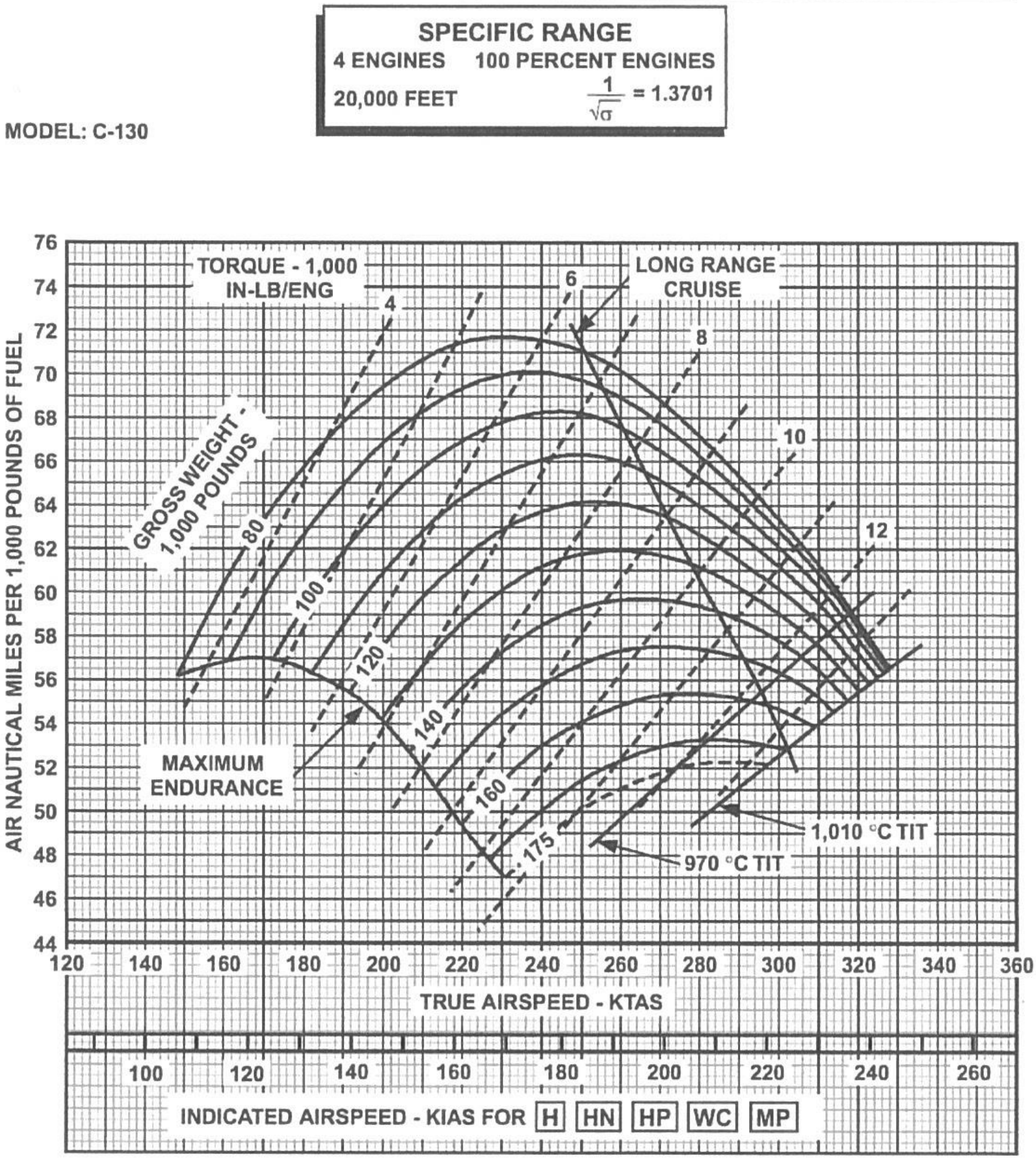

Fig. 3.10 Specific range at 20000FT

In first situation, range obtained is 64 nautical miles for 1000 lbs of fuel consumed, while in situation 2, it will be reduced with 3,15, becoming 60,85. There is a decrease in range by 4,92 %.

9. Specific range at 25000FT

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs	Weight 121500 lbs
ZFW = 87892 lbs	ZFW=89392 lbs
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 25000FT	Altitude - 25000FT
Temperature - standard conditions	Temperature - standard conditions

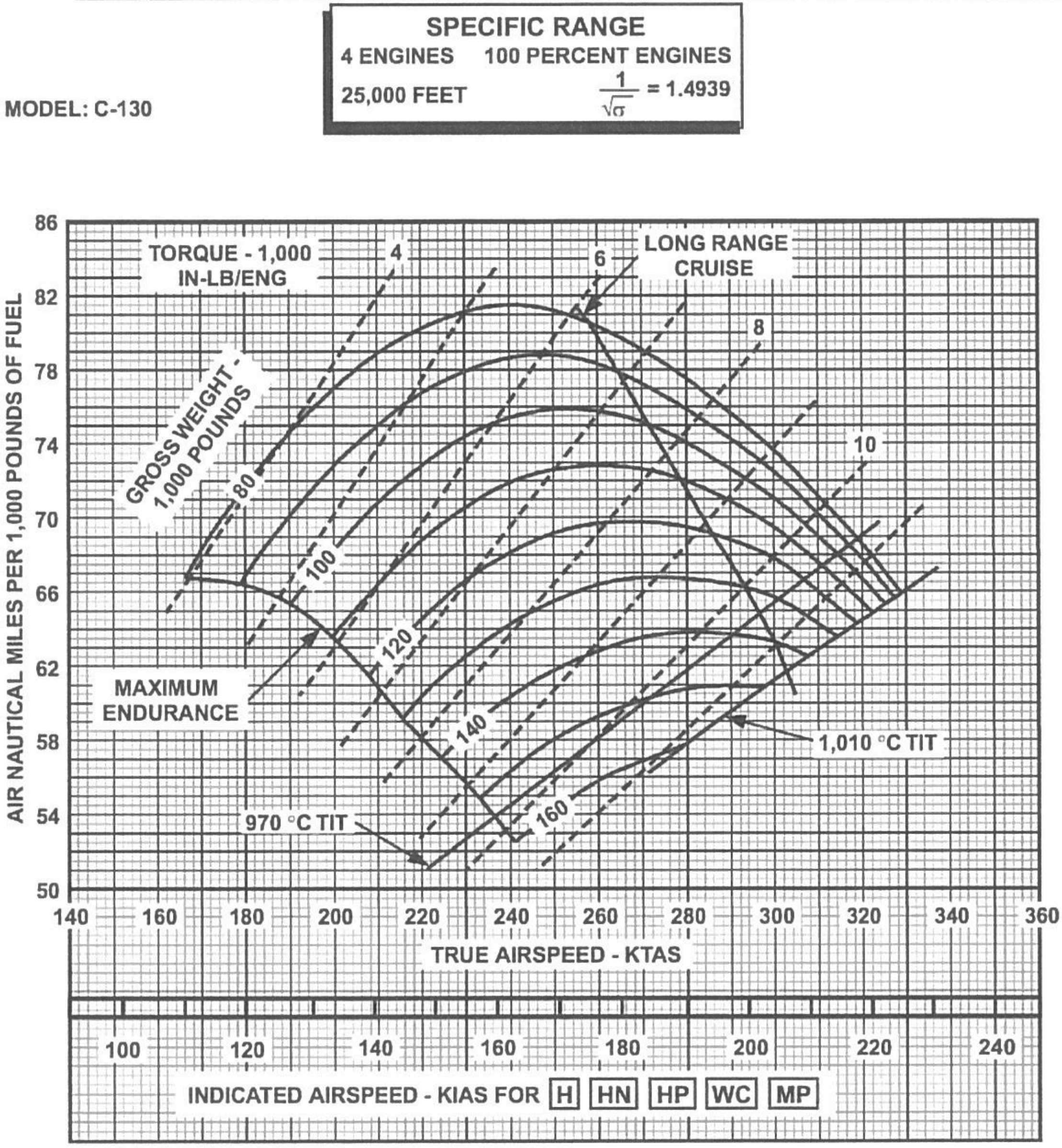

Fig. 3.11 Specific range at 25000FT

In first situation, range obtained is 69,5 nautical miles for 1000 lbs of fuel consumed, while in situation 2, it will be reduced with 4,5, becoming 65. There is a decrease in range by 6. 47%.

10. Specific range at 30000FT

Without spare parts warehouse (1)	With spare parts warehouse (2)
Retracted train-flaps configuration	Retracted train-flaps configuration
4 engines - 100% efficiency	4 engines - 100% efficiency
Weight 120000 lbs	Weight 121500 lbs
ZFW = 87892 lbs	ZFW=89392 lbs
180 knots speed (IAS)	180 knots speed (IAS)
Altitude - 30000FT	Altitude - 30000FT
Temperature - standard conditions	Temperature - standard conditions

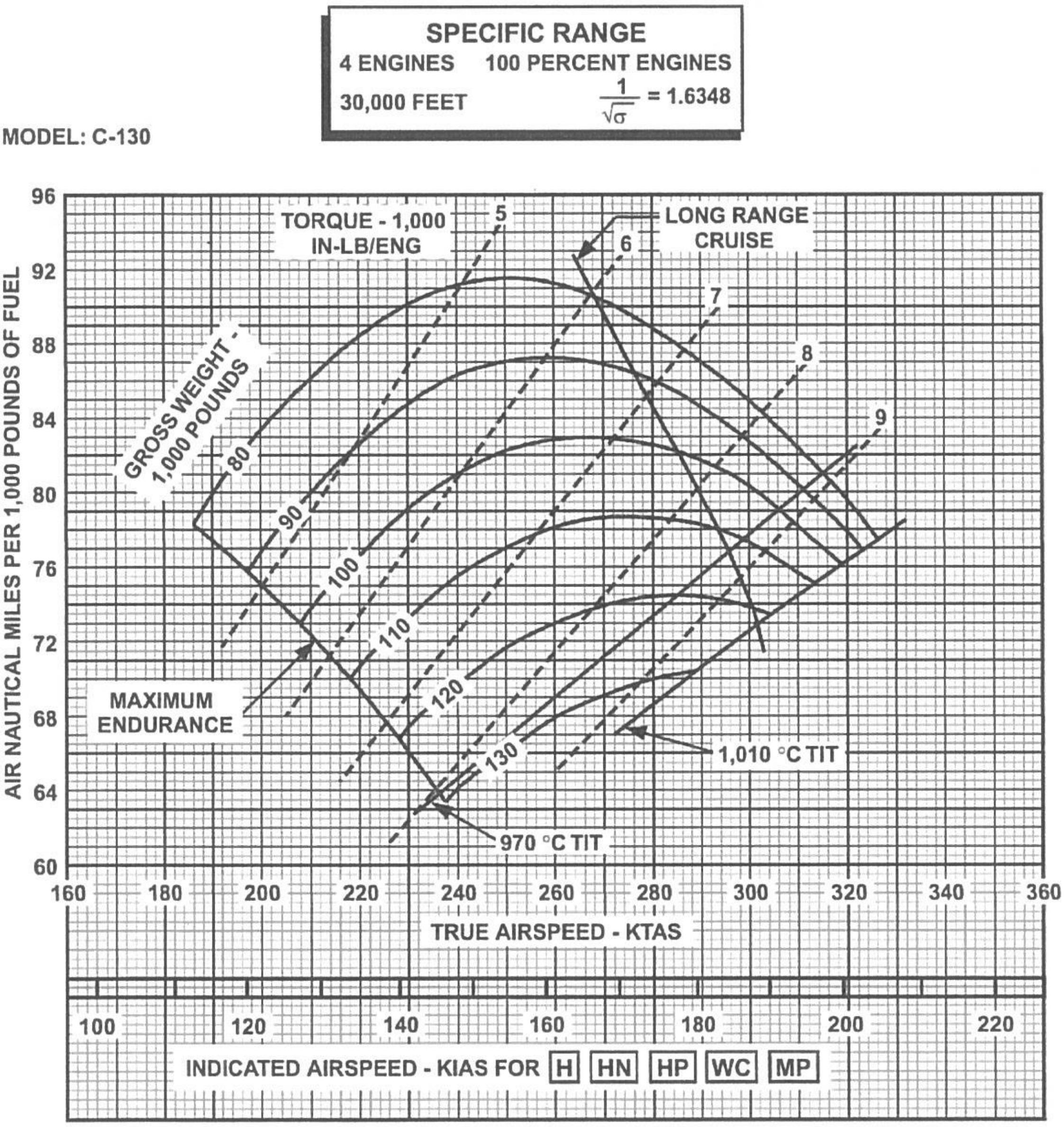

Fig. 3.12 Specific range at 30000FT

In first situation, range obtained is 74,5 nautical miles for 1000 lbs of fuel consumed, while in situation 2, it will be reduced with 5,25, becoming 69,25. There is a decrease in range by 3. 47%.

The purpose of this subchapter was to calculate the influence of the additional weight on board the aircraft, generated by the parts warehouse and the technical team needed to perform the corrective maintenance work. The best way to find out this influence is to find out the increase in consumption generated by the extra weight and to calculate the range.

In terms of low altitude consumption, for a takeoff weight of 120,000 lbs, calculated in different configurations, an increase of 3.3 percent was achieved on average.

As it is already known, any extra weight loaded reduces the maximum flight distance, so this increase in consumption was also reflected in the autonomy of the aircraft, obtaining a decrease, on average, of about 4.71 percent.

These calculations are valid if the load of the aircraft is not so high as to increase the take-off weight to the maximum value. Precisely for this reason, the performance calculations were made for a weight of 120,000 lbs. As the aircraft is loaded with the maximum amount of payload, the amount of fuel it can refuel is limited by the maximum take-off weight, in which case the range is limited by the amount of fuel on board.

Therefore, the exchange will be made between the load and the amount of fuel, from which it can be deduced that the stock of parts will not affect the autonomy but will lead to a decrease in the amount of materials that can be transported. An acceptable exchange, as long as the flight will be executed safely, and the chances that the aircraft and crew will remain immobilized at a stopover, reserve airport or in the theater of operations will be almost non-existent.

CONCLUSIONS

C.1. General conclusions

Maintenance aims to ensure the operation of technical systems and equipment. This purpose can only be achieved by addressing appropriate measures to maintain or restore the functional parameters of the system/equipment, in compliance with the required quality conditions.

Intuitively in the process of defining requirements, the evaluation of specifications and the system is the aspect of identifying the appropriate quantitative measures of logistics for a given system configuration. These measures can, of course, vary from system to system, as customer needs and mission requirements will vary from application to application. In addition, there can be several factors for any given situation. Thus, it is impossible to cover all the conditions and it is certainly not possible within the following limits. However, qualitative measures of logistics need to be addressed.

In order to cover all maintenance requirements, it is essential that all aspects involving the operation of the system are taken into account on an integrated database, and it must contain not only segments oriented towards the execution of the mission itself, but also the capacity to provide logistic support.

However, existing methods are not always easy to apply, where availability is often a more important criterion than reliability, in other words, downtime is more important than a low probability of failure. An error is acceptable if the repair and restart times are short, therefore the maintainability of the system and ensuring an efficient maintenance process are the key to the success of the mission in most cases.

As it was presented during the thesis, every time a system fails, it is necessary to follow a series of steps to restore it to the state of operability. These steps include: diagnosing the defect, isolating it, disassembling the equipment to gain access to the defective part, and repairing it.

In order to meet the requirements of the system, the usual tendency is to address first those elements of it, which have direct implications for operation, but very little attention is paid to maintenance and logistical support for the whole system, especially to ensure the fulfillment of missions at maximum performance.

In order to ensure that appropriate logistics are addressed throughout the life cycle, there must be adequate logistical support requirements, even during the conceptual design phases of the system. Logistical requirements must be specified initially, both quantitatively and qualitatively. As the system evolves, the defined configuration must be assessed against the specified requirements, and changes for improvement must be incorporated as necessary to ensure effective results. This assessment task, which is an iterative process, is accomplished through a combination of predictions, analyzes, and the use of physical models to perform tests and demonstrations.

C.2. Personal contributions

The aim of the research was the analysis of the complexity of maintenance activities performed in international military theaters of operations, for C-130 Hercules aircraft used by the Romanian Air Force, to fulfill the full range of missions in which they are engaged, effectively using modern research methods. Its final purpose is to draw up the minimum operational stock of parts with which the aircraft should go on air transport missions in order to meet them at maximum parameters.

This analysis started from the need to discover the critical components of the aircraft, namely those with the highest failure rate. To this end, personal contributions are highlighted, listed below:

- Was studied and systematized the bibliography related to the description of the maintenance activity;
- Was prepared a situation with the failures of two aircraft, between January 2018 and December 2019;
- Were identified and statistically analyzed the corrective maintenance activities by types of specialties.

The observations for each technical system are detailed below:

a) Structure components

Most structure components failures were detected during the preliminary flight preparation, as 26 out of 54 total cases. It is to remark that preventive maintenance and the monitoring system are highly efficient.

The main cause of defects is the wear, as 32 out of 54 total cases, most likely due to their age and the vibrations that affect the cell and its aggregates. The RPN could be considerable modified, as 75%, mainly by decreasing the failure frequency (F). Thus, it can be deduced that the detection methods have a high yield, but initial F is characterized by a high value; the critical situations can be reduced by identifying as accurately as possible the aggregates with a high risk of failure and replacing them with some with higher reliability, adapted to the operating conditions (temperature, vibration, corrosion, etc.). This entails additional maintenance costs, but it is justified by higher aircraft availability and increased operational safety.

Existing methods for monitoring the system are sufficient to detect faults before they occur, in most cases. In some cases, the defects are caused by the relatively low reliability of the parts, but this can increase and lead to a decrease in the frequency of defects, even involves additional costs.

b) Engine components

Most of the failures occurred during the flight and were mainly caused by clogging of the injectors and filters (from the lubrication system, fuel and hydraulics), which leads to the conclusion that preventive maintenance and monitoring system in technical systems of the engine type it is not carried out at maximum efficiency. Another important factor is the wear of the components, a somewhat normal situation, due to their age and the stress to which they are subjected due to high vibrations and temperatures inside/outside the engine, which decisively affect them.

It was possible to improve the RPN, in a large percentage, 74%. Like the analysis for structure technical systems, the engine-type systems involve the necessity to identify components with a high risk of failure and replace them with more reliable ones, adapted to operating conditions, with additional costs to ensure a proper maintenance.

It is necessary to streamline preventive procedures in order to reduce the probability of failure, by implementing predictive detection methods by using statistical detection methods and by compiling databases with defects found in the operation and highlighting the occurrence of new defects.

c) Radio components

Among the causes underlying the occurrence of failures, it is observed that wear is by far the main reason, having the highest percentage compared to other specialties. Radio parts are sensitive to vibrations with high amplitudes and exposed for a long time (taking into account their age). The RPN could be changed in a lower percentage compared to other specialties, but the rule of improvement is maintained, it is optimized by reducing the frequency of failures in most situations. This can be influenced both by identifying the aggregates prone to damage, wear, corrosion, condensation, etc. as well as by replacing them with some with a high reliability, purchased directly from the manufacturer. Detection methods can also be improved by specializing maintenance personnel in order to be able to identify in the structure of the aggregates, the components with lower reliability. It should be emphasized that the method entails additional maintenance costs, the adoption of which is dictated by the value of the investment.

d) Special systems

Most of the failures were identified during the flight (60%), a result which is the same as in the case of radio-type systems because some of the aggregates start only after take-off, for example the wing and empennage deicing installation. Almost a third of defects were detected during preliminary preparation and pre-flight inspection, indicating that preventive maintenance and the monitoring system have a good efficiency. It is therefore necessary to streamline preventive procedures in order to reduce the number of inflight failures.

The main factor leading to failures is again wear, especially due to the age of the aircraft and thus the aggregates.

The RPN could be improved, by reducing the frequency in the most of the cases and can be imposed measures that can influence it both by identifying the aggregates prone to wear, corrosion, etc., and replacing them with more modern ones. and technically superior.

- Was calculated the reliability of the main components and were identified the critical components;
- Following their finding and the application of maintenance analysis methods, was drawn up the minimum operational stock of parts necessary to fulfill the air transport mission in the theaters of operations at the maximum parameters;
- Was studied the influence on the aircrafts performance, caused by the additional weight generated by the presence on board of the warehouse and of the technical team that will perform the maintenance works;
- Were calculated the consumption, range and endurance of the aircraft, in both situations, with and without the warehouse on board.

Finally, the additional weight on board, generated by the warehouse and the technical team, will not affect the autonomy but will lead to a decrease in the amount of materials that can be transported. It can be considered an acceptable exchange, as long as the flight will be performed safely, and the chances that the aircraft and crew will remain immobilized at a stopover, alternate airport or in the theater of operations will be almost non-existent.

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