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Concept development and preliminary design of an innovative aerial component for the Italian firefighting system

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Abstract

The present work deals with the firefighting system in Italy and in particular with the aerial support to the firefighting operations. Through an in-depth analysis of the structure and operative procedures of the firefighting system in Italy and in the major countries which adopt a significant aerial component in the wildfire exinguishing activities, strong and weak points have been identified, as well as possible areas for improvement. A significant innovation would be the integration of a new element in the scenario, based on a novel type of spotter aircraft endowed with command and control capabilities in addition to an appropriate sensor suite for wildfire identification and monitoring. These new capabilities would provide a new figure, the COA (Coordinatore Operazioni Aeree), with the necessary tools to greatly enhance the effectiveness of aerial firefighting operations. The COA would operate strictly under the command of the local Incident Commander, without conflicting with the current Italian law and regulations. The work proposes the preliminary design of a special version of an existing airplane, the Piaggio P.166, to fulfil the new role. On one hand, the new airplane would be able to execute prolonged patrol missions, with a dedicated remote sensing suite to spot wildfires in their initial stage, as well as direct the firefighting units precisely and timely on site. On the other hand, the same avionic dowry would allow the aircraft to become and integrated command and control airborne platform capable of coordinating the subsequent operations from a favorable and safe position. The work includes the design of an appropriate workstation, the selection of the necessary avionic components, as well as other implementation issues, with the aim of envisioning a viable improvement to the current situation and its many limitations.

Keywords: firefighting, aerial firefighting, spotter aircraft, disaster management.

Sommario

Il lavoro presentato verte sul sitema di antincendio boschivo in Italia, in particolare del supporto delle operazioni di antincendio aereo. Attraverso un'analisi approfondita della struttura e delle procedure operative del sistema di antincendio boschivo italiano e nelle maggiori nazioni mondiali che adottano la componente aerea come mezzo di soppressione degli incendi boschivi, sono stati identificati i punti forti e le debolezze nelle varie aree di interesse per un potenziamento della struttura italiana per l'antincendio boschivo. Una significativa innovazione potrebbe essere l'integrazione di un nuovo elemento nello scenario, basato su un nuovo tipo di aereo di ricognizione con la capacità di controllo e comando in aggiunta ad una suite di sensori remoti, atti all'identificazione ed al monitoraggio. Queste nuove capacità hanno bisogno di una nuova figura, il COA o Coordinatore Operazioni Aeree, che con i necessari strumenti può incrementare l'efficenza delle operazioni aeree di spegnimento degli incendi. Il COA opererà sotto lo stretto comando del Direttore Operazioni Spegnimento presente nell'area dell'incendio, senza entrare in conflitto con le sue decisioni, in accordo con la normativa antincendio presente in Italia. Il lavoro prosegue con una proposta di progetto preliminare di una versione ad hoc di un velivolo esistente nella flotta delle forze armate italiane, il Piaggio P.166, in modo da coprire il nuovo ruolo proposto. Esso sarà in grado di portare a termine missioni di pattugliamento prolungato, con una suite di sensori remoti dedicati in modo da poter identificare gli incendi boschivi nella loro fase iniziale, allo stesso tempo deve essere in grado di comunicare ai centri di controllo di quali risorse antincendio ha bisogno in modo da guidare le unità in modo preciso e veloce. L'avionica installata a bordo permetterò all'aeroplano di diventare una piattaforma aerea di controllo e comando, atta a coordinare le successive operazioni di spegnimento da una posizione tattica favorevole e sicura. Il lavoro include il progetto di massima di una postazione di controllo, con la selezione dei necessari componenti avionici con le appropriate implementazioni, con lo scopo di prevedere un miglioramento della situazione corrente e delle molte limitazioni che esistono ad oggi nell'antincendio boschivo.

Parole chiave: antincendio, antincendio aereo, velivolo da ricognizione, gestione dei disastri.

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Contents

1 INTRODUCTION **3**

I MISSION ANALYSIS **7**

2 HYSTORY OF AERIAL FIREFIGHTING **9**

2.1 The dawn 9
2.2 A new era 11
2.3 Helicopters 14
2.4 Preface to the aerial firefighting techniques 15

3 WILDFIRES ENVIRONMENT **17**

3.1 Wildland fire behaviour and effects 17
3.1.1 Heat 18
3.1.2 Fuel 19
3.1.3 Oxygen 20
3.1.4 Fire behavior 20
3.2 Description of a fire 21
3.2.1 Parts of a fire 23
3.3 Aerial firefighting tactics 28
3.3.1 Preface 28
3.3.2 Tactics in firefighting 29
3.3.3 Aerial firefighting techniques 32
3.4 Aerial fighting materials 39
3.4.1 Fire retardants 39
3.4.2 Water 40

4 AIRCRAFT USED FOR FIREFIGHTING PURPOSES **41**
4.1 Fixed-wing 42
4.1.1 Air tactical aircraft 42
4.1.1.1 Command planes 42
4.1.1.2 Lead planes 43
4.1.1.3 Transport aircraft for smokejumpers 43
4.1.2 Water bombers 44
4.1.2.1 Very large airtankers 45
4.1.2.2 Type I – The "large airtanker" 45
4.1.2.3 Type II – The small "large airtanker" 46
4.1.2.4 Type III – The "medium airtankers" 46
4.1.2.5 Type IV – The "small airtanker" 47
4.2 Helicopters 47
4.2.1 Size classification 48
4.2.2 Mission classification 48
4.2.2.1 Fire helicopters 48
4.2.2.2 Helitanker 49
4.2.2.3 Helitack 50

5 FIREFIGHTING ORGANIZATIONS: MAIN CASE STUDIES IN THE WORLD **51**
5.1 Incident command system 52
5.2 United States of America 54
5.2.1 Firefighting organization 54
5.2.2 Aviation operations 58
5.2.2.1 Aerial resource management 60
5.2.3 Financial arrangements 61
5.3 Canada 62
5.3.1 Firefighting organization 62
5.3.2 Aviation operations 65
5.3.2.1 Aerial resource management 66
5.3.3 Financial arrangements 67
5.4 Australia 67
5.4.1 Firefighting organization 67
5.4.2 Aviation operations 70
5.4.2.1 Aerial resource management 71
5.4.3 Financial arrangements 72
5.5 France 73

5.5.1 Firefighting organization 73
5.5.2 Aviation operations 77
5.5.2.1 Aerial resource management 78
5.5.3 Financial arrangements 79

6 THE ITALIAN CASE 81
6.1 The italian forest fire organization 82
6.1.1 Italian agencies cooperating in wildifre suppression . . . 87
6.2 The aerial component in italian firefighting 90

7 MISSION ANALYSIS CONCLUSIONS 95
7.1 Managing firefighting 95
7.1.1 Scientific approach 96
7.1.2 Continous training 97
7.2 Fire operations 99
7.2.1 Aviate, navigate, communicate and manage – In that order 100
7.2.2 Wildfire environment for air traffic 101
7.2.3 Italian utilization of the aerial component in firefighting . 103
7.2.4 Processes optimization 110
7.2.4.1 Aerial surveillance 111
7.2.4.2 Aerial survey 112
7.2.4.3 Command chain optimization 113
7.3 Information flow 115

8 POSSIBLE SOLUTIONS 117
8.1 *Coordinatore Operazioni Aeree* (COA) 117
8.1.1 The right size of aerial supervision in Italy 118
8.1.2 COA duties 120
8.1.3 Suppression organization improvements with coa figure introduction 121
8.1.4 Conclusions 122
8.2 Environment incident aerial surveillance aircraft 123
8.2.1 Wildfire figthing mission scenario 124
8.2.1.1 Patrolling 124
8.2.1.2 Supervision 124
8.2.1.3 Survey 125
8.2.2 Remote sensing suite solution 125
8.2.3 Alternative missions 126

8.2.3.1 Alternative land survey missions 126
8.2.3.2 Alternative civil protection emergencies missions 127
8.3 Conclusions 128

II INNOVATIVE SPOTTER AIRCRAFT SYSTEM DESIGN 129

9 REMOTE SENSING 131
9.1 Introduction 131
9.1.1 Remote sensing, GPS and GIS integration 132
9.1.2 Remote sensing and disaster management 135
9.2 Sensor description and operational use 139
9.2.1 FLIR turret 141
9.2.1.1 Description 141
9.2.1.2 Operational use 142
9.2.2 LiDAR 147
9.2.2.1 Description 147
9.2.2.2 Operational use 150
9.2.3 Aerial photography 158
9.2.3.1 Description 158
9.2.3.2 Operational use 162
9.2.4 Synthetic aperture radar 164
9.2.4.1 Description 164
9.2.4.2 Operational use 166
9.3 Conclusions 170

10 COMMAND STATION 171
10.1 Introduction 171
10.2 Control station architecture and sensor integration 171
10.2.1 Aircraft remote 172
10.2.2 Cabin and avionics 173
10.2.3 Tactical console 175
10.2.4 Command station overview 180
10.3 Utilization modes, a description 180
10.3.1 Active control mode 181
10.3.2 Survey mode 182
10.3.3 Search and rescue mode 184

11 AIRCRAFT INTEGRATION **185**
11.1 Choice of platform 185
11.1.1 Requirements 185
11.1.1.1 Aircraft design 186
11.1.1.2 Aircraft performances 192
11.1.1.3 Conclusions 194
11.1.2 Italian aircraft availability 195
11.1.2.1 P.166 and spotter aircraft comparison 198
11.1.2.2 Conclusions 206
11.1.3 Piaggio P.166 overview 207
11.2 P.166 integration with remote sensing suite 214
11.2.1 Sensor integration 214
11.2.1.1 LiDAR integration 215
11.2.1.2 Aerial camera integration 217
11.2.1.3 COA display 219
11.2.2 Integration analysis 220
11.2.2.1 Spotter aircraft layout 221
11.2.2.2 Sensor installation 225
11.2.2.3 Weight and balance 226
11.2.2.4 Four crew load and fuel near to MTOW 230
11.2.2.5 Three crew load and fuel near to MTOW 231

12 SYSTEM IMPLEMENTATION **233**
12.1 Cost of the system 233
12.1.1 Real cost data 234
12.1.2 Analytical methods 234
12.1.3 Proportional evaluation 234
12.2 Operative scenario 236
12.2.1 Cost saving 236
12.2.2 Number of aircraft to refurbish 237
12.3 Other missions for P.166 DP1/AIB 239
12.3.1 Disaster emergency 240
12.3.2 Environmental control and cadastral patrol 240
12.3.3 Light maritime patrol 240
12.4 Future developments 241
12.4.1 Spotter aircraft 241
12.4.2 Interaction between spotter aircraft and bombers 241

13 CONCLUDING REMARKS **243**

List of Figures

2.1 Grumman Avenger modified for firefighting duties. 11
2.2 Canadair CL-415. 14

3.1 Fire triangle. 18
3.2 Fire nomenclature. 22
3.3 Parts of a fire 23
3.4 Types of tactics in direct attack. 25
3.5 Parallel attack 26
3.6 Indirect attack scheme. 27
3.7 Water bomber standard run 32
3.8 Changing tactics consequently a wind direction variation 33
3.9 Flanking tactic. 33
3.10 Tandem ahead. 34
3.11 Tandem behind. 34
3.12 Hook. 35
3.13 Narrow vee and wide vee. 35
3.14 Angle tie-in. 36
3.15 Spot fire. 36
3.16 Pre-treat 37
3.17 Angle out 37
3.18 Cooling convection current. 38
3.19 Spot field cover. 38

4.1 Bambi bucket operations 49
4.2 Sikorsky S64-F Skycrane 50

5.1 ICS organization tree 53
5.2 USA organizational diagram 54
5.3 GACC location in USA 57

5.4 Canadian organization model. 62
5.5 Australian organization scheme 68
5.6 AFAMS synthetic function scheme. 72
5.7 Organizational chart of the French Ministry of the Interior. . . . 73
5.8 COGIC organizational chart. 74
5.9 COZ organizational chart. 75
5.10 CODIS organizational chart. 76
5.11 Aerial bases of *Sécurité Civile.* 78

6.1 Fire risk in the first and third trimester of the year. 82
6.2 Command chain scheme for firefighting activation. 84
6.3 Command chain of aerial intervention over a fire. 86
6.4 Department of civil protection organizational chart. 88
6.5 Italian Regional fleets in 2013. 90
6.6 Differences between 2012 and 2013 years of resources deployements and bases used in Italy for firefighting. 92
6.7 SNIPC functioning diagram. 92

7.1 Airspace volume for firefighting operations. 102
7.2 Tipical pattern for every type of aircraft involved in a firefighting mission. 103
7.3 Decisional parameters for FFDI and first attack time. 105
7.4 Trend lines with various parameters of probability to success in wildfire suppression. 106
7.5 Firefighting productivity for a CL-415 in relation to the distance between scooping zone and wildifre location. 107
7.6 Summer Firefighting activity in Italy. 109
7.7 Example of active patrol patterns of french water bombers. . . . 111

8.1 Initial attack organization in USA. 119
8.2 Extended attack organization in USA. 119

9.1 Linear model diagram 133
9.2 Interactive Model Diagram 133
9.3 Hierarchical Model Diagram 134
9.4 Complex Model Diagram 135
9.5 Disaster Management flow chart 136
9.6 Selected examples of measures of active fire characteristics.[40] . 140
9.7 LiDAR scheme. 148

9.8 LiDAR functioning principle. 149
9.9 LiDAR returns examples. 150
9.10 Canopy fuel metrics. 153
9.11 Multiple LiDAR returns from the canopy (A), the understory (B), and ground (C) displayed above a digital terrain model (D) interpolated from ground data.[50] 154
9.12 The digital surface model (A) shows the true elevation of the top of the canopy, the digital terrain model (B) shows the underlying surface elevation, and the digital canopy model (C) shows vegetation and tree heights. The digital canopy model (C) is created when the DTM (B) is subtracted from the DSM (A).[50] 155
9.13 Building methods for forest characteristics with LiDAR and Aerial Imagery fusion. 157
9.14 Products of aerial phorography. 158
9.15 Elements of aerial photography. 160
9.16 Camera orientation types. 161
9.17 Aerial imagery examples. 161
9.18 Aerial photgraphy flight pattern. 162
9.19 Near infrared photography for burned surface analysis. 164
9.20 Airborne SAR functioning principle. 165
9.21 Basic block diagram of typical SAR system. 165
9.22 SAR ground errors. 166
9.23 SAR imagery of a wildfire. 167
9.24 Surroundings of Rochambeau Airport, French Guyana. The green color indicates a "depolarization" of the incident wave back-scattered by the medium, which is greater the denser the vegetation.[59] . 169

10.1 Block diagram of layers connection. 172
10.2 Generalized block diagram of aircraft remote layer. 172
10.3 Aircraft remote block diagram customized for firefighting spotter aircraft. 173
10.4 Avionic tier block diagram. 173
10.5 Communications block diagram. 174
10.6 Flight management system block diagram. 175
10.7 Tactical console block diagram. 176
10.8 TCAS II block diagram example. 178
10.9 Functioning criteria of TCAS II. 179
10.10TCAS II display example. 179

10.11 Command station integration overview. 180
10.12 Active control mode logic. 181
10.13 Survey mode logic. 183
10.14 SAR mode logic. 184

11.1 High wing configuration layout example. 187
11.2 Aeronautical engines typical utilization range. 188
11.3 Engine range of use in relation to altitude. 189
11.4 Propeller engine types of installation. 190
11.5 Aircraft used in comparison. 192
11.6 Gull wing examples. 198
11.7 Payload weight comparison related to MTOW. 200
11.8 Percentage amount of single weight component in MTOW. . . . 200
11.9 Internal dimensions comparison. 201
11.10 Internal cabin volume comparison. 202
11.11 Take-off distances comparison. 203
11.12 Landing distances comparison. 205
11.13 Speed comparison. 206
11.14 Maximum endurance comparison between aircraft. 206
11.15 Piaggio P.166 DP1 of Italian Coast Guard. 207
11.16 Three view Piaggio P.166. 212
11.17 Three view Piaggip P.166 with nose radome version. 213
11.18 LiDAR comparison. 215
11.19 LiDAR sensor weight comparison. 216
11.20 LiDAR sensor volume comparison. 216
11.21 Component weights comparison for aerial cameras. 217
11.22 Sensor weight for aerial cameras comparison. 218
11.23 Aerial cameras volume comparison. 219
11.24 FD101DDARM-ML display. 220
11.25 Zone of intervention. 221
11.26 Piaggio P.166 interior configuration layout. 222
11.27 Nose radome detail. 223
11.28 Cabin layout in SEM configuration. 223
11.29 Bubble window detail. 224
11.30 Bubble window installation zone. 224
11.31 COA workspace zone. 224
11.32 Utility compartment dimension. 226
11.33 Weight and Balance in a typical firefighting mission. 230

11.34 Loadsheet for firefighting mission. 231
11.35 Weight and Balance in survey mission. 231
11.36 Loadsheet for a survey mission. 232

12.1 Cost esteem diagram. 235
12.2 Break even point diagram. 236
12.3 Italian water bomber deployement. 238
12.4 Piaggio P.166 DP1/AIB deployement envision. 239
12.5 Canadair CL-415 in action. 242

List of Tables

4.1 ICS Airtanker Classification[9] 44
4.2 Helicopters classification.[7] 48

7.1 Number of fires and total surface burned in Italy. 108
7.2 Differences between 2011 and 2012 years in summer aerial forest firefighting activity. 109

9.1 Differences between LiDAR and Aerial Imagery.[53] 156
9.2 Differences in surface discrimination properties between LiDAR and Aerial Imagery.[53] 156

11.1 Choose criteria between the three possible vertical position of wing.[63] 187
11.2 Spotter airplanes used in countries analyzed in first part of thesis. 191
11.3 Principal dimensions of aircraft used in comparison. 192
11.4 Take off and landing performances. 193
11.5 Italian fleet performances, mission endurance is based on statistical average on last year interventions.[65] 193
11.6 Endurance and speed performances for aircraft used in comparison. 194
11.7 Requirements summary. 194
11.8 Transport and special mission aircraft used by Italian Air Force.[66] 195
11.9 Transport aircraft used by Italian Army.[66] 195
11.10 Transport aircraft used by Italian Navy.[66] 195
11.11 Special mission aircraft used by Italian Coast Guard.[67] 196
11.12 Special mission aircraft used by Italian State Police.[68] 196
11.13 Special mission aircraft used by Carabinieri.[69] 196
11.14 Special mission aircraft used by *Corpo Forestale dello Stato*.[70] 196
11.15 Special mission aircraft used by *Guardia di Finanza*.[71] 196
11.16 Number of P.166 used in Italian Air Force (2012 data).[72] . . . 197

11.17 Number of P.166 used in Italian Coast Guard (2012 data).[72] . 197
11.18 Number of P.166 used in *Guardia di Finanza* (2012 data).[72] . 197
11.19 Comparison between the MTOW components for each aircraft used in analysis. 199
11.20 Internal dimensions summary. 201
11.21 Internal cabin volume overview. 201
11.22 Take-off performances. 202
11.23 Landing performances. 204
11.24 Normal operation speed. 205
11.25 Maximum endurance. 206
11.26 LiDAR airborne sensors used in comparison.[79] 215
11.27 LiDAR sensor volume comparison.[79] 216
11.28 Aerial cameras component weights. 217
11.29 Mean values for aerial cameras in realtion to size. 217
11.30 Aerial cameras volumes. 218
11.31 Volume mean values for aerial cameras. 219
11.32 COA display specifications.[100] 219
11.33 Baggage compartment door dimensions. 225
11.34 Utility compartment dimensions. 225
11.35 Utility compartment and sensors dimensions comparison. 226
11.36 Piaggio P.166 DP1 weights. 227
11.37 Extracted weights. 227
11.38 Weight and balance components of new item installed. 228
11.39 Eright and balance components of item disembarked. 228
11.40 New empty weight equipped and new maximum payload after modification. 228
11.41 New center of gravity position with the modification. 229
11.42 Crew disposition in new configuration. 229
11.43 Fuel tanks weight and moment components. 230

12.1 Unit prices of similar equipped aircraft. 234
12.2 Cost esteem. 235
12.3 Cost of wildfires in relation to size.[78] 237
12.4 Cost saving percentage.[78] 237

Chapter 1

INTRODUCTION

This thesis is the natural evolution of the work carried out for the "Aircraft Design" course at the Politecnico di Milano in the 2011/2012 academic year. The aim of the project was:

"To investigate the possibility of meeting the needs of firefighting in a large Mediterranean country in Europe (Italy, France, Spain), integrating an aircraft fleet of the Bombardier 415 type with smaller aircraft, which need to be certified according to the CS-23 normative and be able to be used throughout the territory, to have minimum structural requirements and a high operational flexibility. To design such an aircraft, taking into consideration that it needs to be able to carry out extra operational tasks, which will also need to be identified, in order to decrease the impact of firefighting seasonality on the designing and managing costs."

During the preliminary project, whilst examining the Italian firefighting environment, we noticed some weaknesses in the Italian aerial firefighting system. This work is an in-depth analysis of the Italian wild firefighting scenario, with particular attention to the aerial component of firefighting. Its aim is to find solutions as regards to the optimization of extinguishing operations, the reduction of aircraft costs in suppression missions and the evaluation of the efficiency of the command chain used during normal operations.

The discussion is composed of two main parts: the first part explains the mission analysis, while the second one looks at the practical implementation and design of the solutions proposed.

The mission analysis refers to all aspects of aerial firefighting, from a historical point of view to an operational explanation of the tactics used for a better awareness of the operative environment. The thesis proceeds with a comparative study of the four major countries which fight actively against wildfires, namely USA, Canada, Australia and France. Some solutions are evaluated and selected to apply to the Italian case, which require a few, but significant modifications in the aerial firefighting organization, in order to maximize the performance of the Italian system. These modifications specifically involve the proposed introduction of a new role in the aerial firefighting scenario, the COA (Coordinatore Operazioni Aeree), and of a new mission type, carried out by a specially designed spotter aircraft. The COA acts as a coordinator of the aerial component in the theater of operations above a wildfire, is in direct contact with the director of extinguishing operations, evaluates the incident situation and provides information to the director. The COA leads all aerial operations and all pilots follow his information and target indications. All these operations must be carried out on a specific aircraft, different from that used in many other countries. This innovative *spotter aircraft* has two important roles: the first role is to patrol the territory during high wildfire risk seasons, in order to detect new fires and to achieve a faster response in extinguishing them; the second role is to provide a command and control airborne station for the diverse aircraft fleet operating over the wildfire.

The second part is focused on the choice of an airplane in the Italian fleet able to take on the spotter aircraft role, following the historical example of all the firefighting aircraft which were based on reconversions. The design part is divided in three main themes. The first deals with the remote sensor suite selection and with the choice of the best aid for the role. The second is related to the integration of the suite with a command console handled by a Tactical Operator (TACO), and the last part is the selection and reconversion of the aircraft following design and mission criteria. The editing of this work has followed three main methods used in both the parts of the analysis. Firstly, data was collected from scientific papers, publications, websites and databases, in order to study aerial firefighting thoroughly and to discover new solutions to apply to our case. The second method was the most important and proactive, as it involved interviewing several stakeholders and tours in aeronautical companies and in the operative field. The author went to Piaggio Aero Industries based in Genova Sestri to talk with company engineers. In order to understand the operative dynamics of aerial firefighting, the author interviewed several Canadair CL-415 crew, and was guest of the Central Office of the Italian Civil Protection System (Protezione Civile) in Rome. Also, the method laid out in the present work was assessed by further interviews with Italian State Forest Service (CFS, Corpo

Forestale dello Stato) and Italian Air Force personnel working in the operative room of the Italian Civil Protection System. Many incident commanders (DOS, Direttori Operazioni Spegnimento) of the CFS were also interviewed while the author was visiting the aerial corps of Italian firefighters base in Venice. Last but not the least, the Italian customer care manager of Rockwell Collins International, one of the major avionics company in the world was interviewed to provide significant information for the system proposed in this work. Lastly, a design method which adheres to all the criteria described by manuals and legislation in aeronautical matters, was carried out for the remote sensing integration and aircraft reconversion.

The target of the present work is simple: maximizing the performance of the Italian aerial firefighting system, reducing the weaknesses in the operative and bureaucratic fields, in order to have an organized and safe firefighting mechanism. The aim is also to find a solution to compensate for the lack of resources, with the introduction and integration of a new multi-role aircraft for the optimization of the extinguishing operations.

Part I

MISSION ANALYSIS

Chapter 2

HYSTORY OF AERIAL FIREFIGHTING

The United States of America was the first country to use aircraft for firefighting. The American Aerial Firefighting is considered the best example in aviation history. It was founded by a private initiative at the beginning of the '30s when the bush wildfire phenomenon reached a significant dimension all over the country. The devastation reached great proportions, and was exacerbated by the deforestation caused by human activities such as agriculture and farming. From these rudimentary attempts, aerial firefighting has reached a very effective and developed industrial use in just in seventy years, and is now controlled extensively by big aerial working transportation companies. Although firefighting aircraft are very flexible machines and can reach extremely remote locations in a very short time, they would not be able to fulfill their role without the essential ground assistance of human squads, whose task it is to lead and direct them during the extinguishing operations. Aerial firefighting is not only an American prerogative, and it is now widely used in Europe, especially in the Mediterranean countries, where bushfires are most frequent. Nowadays, firefighting fleets are in operation worldwide, and they vary in number and type of aircraft depending on their specific applications.

2.1 The dawn

The first to pioneer aerial firefighting was the "Fire Chief" of the United States Forest Service, Howard Flint who, in the '30s, tried to extinguish a fire with a "liner", a Ford Trimotor, which was the most common aircraft of that time. It was equipped with two handmade tanks under the wings, but the experiment failed because water evaporated before reaching the ground and also because the California University had assumed that the water would be sprayed in the air by the propeller trails with no real effectiveness on the fire. For their second attempt they tried using water bombs. They dropped two 37 liter tanks filled with a liquid product from a height of a hundred meters at a speed of 140 km/h, but the experiment failed again due its mechanical complexity. During the Second World War the experiments stopped. But it was only a temporary break: the huge number of resources that could be recycled from the conflict meant that the water bombing technique was brought back, this time using the dreaded B-29 bomber, also known as Flying Super Fortress, which had been employed during Japanese air strikes. For the first time, the great bomber was used for water dropping experiments in Great Falls (Montana) and because of that, the aircraft was re-named "The Rocky Mountain Ranger". It dropped two types of water bombs from a height of 1000 meters. The first one was equipped with proximity fuses, unlike the second one. Even though they obtained fairly good results, they chose to abandon this technique due to its unsafe use of the metal casing and to the presence of fuses inside it. After six years of studies, in 1953 a solution was found, which allowed water or other types of liquid to cover a vast area. The experiment demonstrated that water dropped from an appropriate altitude and speed reaches the ground wetting the surface proportionally to the quantity of water discharged. During the experiment, a four engine airplane, the transatlantic liner Douglas DC7, which had been equipped with six 1500 liter tanks, was used. They adopted special water-releasing valves to spread the water equally on the ground surface. With this successful attempt a new era began. Since then, Aerial Firefighting has remained unchanged until our time. The following experiments were conducted by Douglas Aircraft and the U.S. Forest Service, with the start of operations in real scenarios in 1954. During that year, the U.S. Forest Service, some Californian institutions and the U.S. Marine Corps worked together in an operation named "Fire Stop". On 1st December 1954, Paul Mantz, an aerobatic pilot, extinguished a fire using a Grumman Avenger, a big single engine anti-submarine aircraft. He was flying at an altitude of 15 meters and sprayed the ground creating a 30 x 90 meter strip. The 2270 liters of water were placed in the ventral vane of the fuselage, in place of the original antisub torpedo. Carrying water using the rubber case of a weather balloon was a brilliant idea, because it allowed the gate valves of the cargo to open and to empty the bladder dropping the water. In the same year, during the Fire Stop operation, helicopters were also used in a firefighting configuration. The Aerial Firefighting operations carried out in the next two years (1955/1956) made an extensive use of a mixture of water and other chemical retardants, used in order to choke the flames. From an idea of a Californian Fire Control Officer, Joseph Ely, who used a Boeing Stearman biplane equipped with sprayers, a company called Air tanker Squadron was born: this had a huge impact on public opinion through the mass media, which reflected the importance of employing aircraft against bushfires.

2.2 A new era

A new era was born. The widespread use of ex-military aircraft became the basis for firefighting. Many corporations were established and the main reason for this growth was the large number of war aircraft available at low cost in the USAF bases. The U.S. Forest Service bought 8 Grumman Avengers which had been modified for firefighting, and many other types of planes were altered for this type of mission. At that time, two-engine aircraft were usually converted, like the Catalina amphibious, the C-82 and the Grumman Tiger-cat bombers.

Figure 2.1: Grumman Avenger modified for firefighting duties.

The Pratt & Whitney R2800 engine was retired as late as in 1992, as it was a masterpiece of reliability and mechanical efficiency. Widely used in airstrikes during the Korean and Vietnam wars, it was now installed on a new tactical machine used for firefighting: the Canadair. In the '60s, after the War in Korea, aircraft like the Douglas B-26 and the Lockheed PV2, formerly used as light bombers and submarine hunters in the US NAVY, were adapted for firefighting. The Lockheed PV2 airplane, equipped with two Wright R-3350 TurboCompound radial engines, was also used in other firefighting aircraft, like the Fairchild C119 and Douglas DC7, due to its exceptional reliability. The Lockheed was an excellent firefighter with a high grade of maneuverability and a high payload of 12500 liters of liquid. The debate of the next decades (from the '60s to the end of the '70s) revolved around how to alter planes as cheaply as possible. Airplanes used for other purposes, such as the B17, a war bomber, or the Douglas liners (DC4, DC6 and DC7), were replaced by the first jet liners. Big and powerful airplanes were modified with external removable tanks with eight independent compartments, with a capacity of 12000 liters of water. The alteration of airplanes turned out to be not only a good idea but an inexpensive and simple solution as well, because it allowed to remove the tank from the airplane easily, allowing the planes to be used for other purposes as well. The aerodynamics of the aircraft wasn't severely affected, as the water dropping system only weighted 600 kg in total. In the '60, s aeronautical firefighting also saw the introduction of heavy weight transporters. One of them was the Martin Mars, an enormous four-engine seaplane equipped with approximately 27000 liters of payload contained in a wooden tank system. The "Philippine Mars" and the "Hawaii Mars", two of these aircraft based in British Columbia, are employed in Aerial Firefighting to this day. During the years in between the '60s and 'the '80s, Aerial Firefighting kept modifying huge ex-military bombers, such as the Douglas B17 and PB4Y-2 (an updated version of B24 Liberator), which are still in use against wildfires in the US. Another mammoth plane used for this purpose was the cargo version of the Boeing 377 Stratocruiser, known as YC97, which was propelled by four engines and capable of dropping 17000 liters of water. Its employment was limited to a short period of time due to its high cost of purchase and management. This trend of maximizing the water payload was interrupted, due to infrastructural problems, such as the need of long take-off runways, the very limited plane maneuverability and the exceptionally high costs. During the same years, thanks to the reconversion of those aircraft and the recycling of the airplanes used on the front line by the armed forces, the Water Bombing field acquired new and powerful airplanes. Nowadays both old and new models are used to extinguish bushfires all around the world. At this point we must make a technical comment. The engine of the aircraft used for this type of mission is not a turboprop or a turbojet engine, but an alternative one. In these airplanes in fact the hot air produced does not influence the functioning of the engine, because of its low-density and because the internal combustion chamber cannot draw parts brought aloft by the hot air of the flames. Contrariwise, the dirty air ingested by the turboprop or jet engine could cause serious damage to the mechanical parts of the engine. At the same time, the superheating of the air could provoke a decrease in engine performance with a severe loss of power, which, in turn, can cause a lot of problems upon water discharge. It is well known that the loss of altitude can turn out to be fatal for the aircraft, especially when considering the terrain conformation and the low altitude at which the firefighting planes usually fly. In the mid '60s we saw the introduction of new airplanes such as the Grumman Tracker, whose tank capacity is about 4000 liters of water, and the Fairchild C119, also known as Flying boxcar. The latter, used mainly in Europe by NATO for middle range transportation, is a double-engined plane with empennage supported by two beams, and it can hold a payload of 10000 liters of liquid. But the undisputed king of aerial firefighting, at that time, was without doubt the Canadair CL-215. At the beginning it was a simple aircraft with two piston engines, but as time passed it was equipped with two turboprop engines, thus evolving into the Canadair CL-415. As well as being an amphibious plane with a retractable landing gear, it can hold a payload of 6 short tons of water. All the above-mentioned airplanes, with the exception of the Canadair and the Martin Mars, are strictly connected to the availability of cement runways and, above all, to the presence of service stations where they can load fireproof liquids. The Canadair and the Martin Mars are in fact amphibious planes that can only fill theirs tanks with the dynamic pressure created by the hull in contact with a body of water. But the reconversion era was not complete. During the '70s the Lockheed Electra too joined the Aerial Firefighting fleet. This plane, set aside by civil aviation for having a lot of problems with the turboprop, was reconfigured in the military version known as PC3 Orion, and was used by both the US and the NATO armies as an anti-submarine aircraft. Nowadays the majority of these converted aircraft, in their older versions, carry out their roles as bombers in a perfect manner. The Lockheed C130 Hercules is an example. It made its debut as a firefighting plane at the beginning of the '80s both in the USA and in Italy (one of the countries with the most bushfire problems). Solid and reliable, the H version of this airplane is particularly used by many NATO countries for military transport. But the Lockheed C130 Hercules, in its J version, is equipped with a module called MAFFS: Modulary Airborne Fire Fighting System. This device is composed of five tanks installed with a modular pallet inside the fuselage, with a total payload of 12000 liters of water and retardant liquid. They are sprayed together by two nozzles positioned in the rear cargo door. The quantity of liquid to be dropped is the pilot's decision, but the well-known problem of re-supply remains. A similar system was developed by the Italian Army and was installed on the double propelled Fiat G-222. However, while in the MAFFS the quantity of water to be discharged is for the pilot to decide, in the Italian aircraft the payload cannot be fractionated, rather, it needs to be expelled all at the same time. Over the years new problems that could only be solved with big investments arose. The availability of ex-military and cheap airplanes decreased and redesigning specific firefighting aircraft from scratch was not a convenient solution. The last airplane to be born in the aerial firefighting scenario was the Russian Beriev Be200, a seaplane powered by a couple of turbojets positioned on the spine of the airplane, in order to protect them from water. It could hold an excellent payload of 12000 liters. Unfortunately this was not the solution to the problem. The aircraft operating in firefighting had accumulated too many flight hours and required frequent maintenance, leading to excessive expenditure.

Figure 2.2: Canadair CL-415.

2.3 Helicopters

It is now time to describe another significant type of aircraft used in firefighting. Fixed wing machines were not the only type of aircraft to be used against bushfires, and rotary-wing aircraft also had a key role in this type of mission. It was during the '50s that operators first tried to use helicopters for firefighting, employing the Sikorsky S58 that could hold a 500 liter payload, , but it was only during the '80s that this new machine confirmed itself as an efficient tool against bushfires. Obviously there are some advantages and disadvantages in using helicopters in firefighting. Some of the advantages are that the bladder is hooked in the center of gravity, the hovering maneuver, which allows the helicopters to refill the buckets even in small bodies of water, and the ability of these machines to approach effectively the front side of fires to drop water accurately. The disadvantages include the high maintenance and operating costs of these machines and the problems that originate from the downdraft of air that can feed the flames with new oxygen. In firefighting scenarios there are various helicopter models for the purpose, from little choppers to very heavy transportation helicopters. All these machines use the same device to combat fires, namely the bucket. The bucket can come in different dimensions and can be installed in twin formation even on large helicopters. A good example of a helicopter used in firefighting operations is the Boeing-Vertol CH47, also called Chinook. It is a twin-rotor troops-transporter formerly used by the Army, equipped with the biggest Bambi bucket on the market, which can hold 5000 liters of liquid. This huge machine was only outclassed by the Russian Mil. Another example of a helicopter used for firefighting operations is Sikorsky S64 Skycrane. This is a multirole aircraft (it was utilized by the US Army during the '60s), with a peculiarity: instead of the bucket used for the majority of helicopters, it is equipped with a tank installed in the central part of the skinny fuselage with two different methods of scooping water. The first system utilized is very similar to the one employed in the Canadair: when water has reached the standard velocity, it comes up in the tanks of the machine. The second system involves a flexible pipe used for suctioning water during a hovering maneuver.

2.4 Preface to the aerial firefighting techniques

In this section we are going to approach the aerial firefighting techniques, omitting for the moment all the preparation and request of aerial support. There are two different methods to engage bushfires. The first one consists of attacking the fire directly. The second one consists of creating a fireline at a safe distance, allowing the fire to advance up to it: this method is used when the size of the head of the fire is particularly big. The system used for firefighting depends not only on the type of payload of the water bombers, but also on the type of attack that we decide to employ in extinguishing bushfire. If the tank is filled only with water, it is preferable to adopt the first technique, attacking the flames directly. The second technique, i.e. the indirect approach, consists in several discharges of water and retardant liquid close to the fire, in order to create a stopping line. In this way the water and, most importantly, the chemical product will be the most effective in repressing the fire. The water-bombers of choice used in firefighting are The Canadairs, for their ability to fill their tanks in bodies of water without going back to the main base. The liquid dropped has a red coloration because it contains iron oxides, which allows firefighters to easily spot which parts have already been sprinkled. Aerial attacks are influenced by many factors. One of them is the conformation of the landscape. An airplane must release its payload during a pitching down moment, allowing the pilot to make the right decision and to select the best release method. Aerial firefighting work would not be as efficient as it is if it wasn't for the critical directions given by the ground squad chief, who is in charge of directing water dropping manoeuvers and of making sure that men and machines work together in an effective and efficient way.

Chapter 3

WILDFIRES ENVIRONMENT

A wildfire is an unplanned, unwanted and uncontrolled fire that occurs in the countryside or in a wilderness area where combustible vegetation is found. Other names such as brush fire, bushfire, forest fire, desert fire, grass fire, hill fire, peat fire, vegetation fire, and veldfire may be used to describe the same phenomenon depending on the type of vegetation being burned. The differences between wildfire and other fires are: its extensive size, the speed at which it can spread out from its original source, its potential to change direction unexpectedly and its ability to jump gaps such as roads, rivers and fire breaks. Wildfire is characterized by its cause of ignition, its physical properties such as speed of propagation, the combustible material and the effect of the weather on the fire. In this paragraph we consider only the type of forest wildfires which are the most common type of hazard where Aerial Firefighters are used. So we can proceed with a short description of forest fires.

3.1 Wildland fire behaviour and effects

There are three elements that can cause a wildland fire and they are described by the fire triangle.

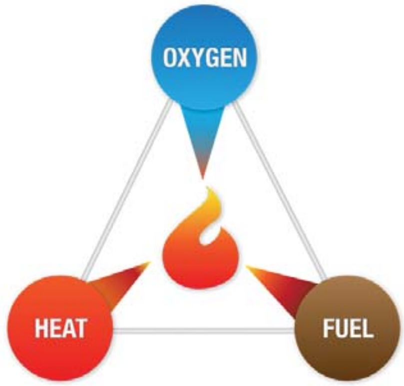


Figure 3.1: Fire triangle.

3.1.1 Heat

It is the primary cause of ignition of the fires and heat transfer is a critical issue for combatting and studying wildland fires. The presence of heat and fuel in the location of the fire cause the flames to grow and spread. One of the most used strategies to combat fire is to mechanically remove the fuel near the flames in order to stop the rapid increase in heat which could make the situation worse. There are three mechanisms of heat transfer:

- Convection: it is the transfer of heat through the flow of liquids or gases, such as when hot air rises through a chimney. Convection currents are often responsible for the preheating of the higher shrub layers and canopy, carrying the ground fire upwards into the canopy.[1]
- Radiation: it transmits heat by rays, such as from the sun or a flame. Radiation accounts for most of the preheating of fuels surrounding a fire. The temperature of these fuels can sometimes rise so high that the fuels ignite prior to contact with flames, spreading the fire.[1]
- Conduction: it moves heat from one fuel particle to the next, as when the stove burner heats a pan and its contents. Conduction allows the heat to be transferred inside and throughout the fuel rather than only heating the surface. Because wood is a poor heat conductor, meaning heat does not pass through it easily, conduction is usually not the primary mechanism of heat transfer in a wildland fire. [1]

3.1.2 Fuel

In a forest there are many factors that can influence a wildland fire. These are: topography, weather and type of vegetation present on the site. The last one is commonly referred to as “fuel” in terms of firefighting. The physical conditions of the wildfire can change according to the combustible vegetation present in the area. Another important factor is where the fuels are located and where the fire is in action. Fuel arrangement and density is governed by the topography, as the features of the landscape determine factors such as available sunlight and water for plant growth. Firefighters divide fuels into three types: this classification helps them decide what the best strategy is to fight the flames. A forest stand consists of several layers of vegetation, created by years of flora activities and it is composed of live and dead vegetation.

- Surface fuels. They consist of grasses, shrubs, litter and woody material lying on the ground. Surface fires burn low vegetation, woody debris and litter. Under the right conditions, surface fires reduce the likelihood that future wildfires will grow into crown fires. [2]

- Ladder fuels. They consist of live and dead small trees and shrubs, live and dead lower branches from larger trees, needles, vines, lichens, mosses and any other combustible biomass located between the top of the surface fuels and the bottom of the overstory tree crowns. [2]

- Crown fuels. Crown fuels are suspended above the ground in treetops or other vegetation and consist mostly of live and dead fire material. When historically low-density forests become overcrowded, tree crowns may merge and form a closed canopy. Tree canopies are the primary fuel layer in a forest crown fire. Fire behavior is strongly influenced by surface, ladder, and crown fuels. Heavy ladder and crown fuels enable fires to climb upward into the crowns and help to sustain crown fires once they are started. Rapidly moving crown fires typically consume nearly all the fine fuels in a forest canopy when wind and a sloping topography are thrown into the mix. Crown fires caused by excessive fuel accumulation are generally a severe threat to ecological and human values and to infrastructure and are a major challenge for fire management. Such fires kill large numbers of trees, damage soils, increase erosion, impair air quality, and can degrade or destroy species habitat. [2]

There are five aspects that we must consider regarding fuels: quantity, vertical arrangement, moisture content, size and shape.

3.1.3 Oxygen

The third side of the fire triangle represents oxygen. Air contains about 21% oxygen; most fires require air with at least 16% oxygen content to burn under most conditions. Oxygen supports the chemical processes that occur during a wildland fire. When fuel burns, it reacts with oxygen from the surrounding air, releasing heat and generating combustion products, e.g., gases, smoke, particles. This process is known as oxidation. [1]

3.1.4 Fire behavior

There are two more important aspects regarding the growth of a fire. They are: weather and topography.

Weather is the most variable of the factors that affect fire behavior. Wildland fires are affected by wind, temperature, and humidity in the burn zone. Strong winds can affect fire behavior by pushing the flames toward new fuel sources. Wind is able to pick up and transfer burning embers, sparks, and other materials that are capable of starting "spot fires." Blowing wind can also serve as a fuel drying source in moist areas. Wildland fires are capable of generating their own wind. Air above the hot flames becomes heated, causing it to rise. This movement allows fresh air to fill the vacuum provided; this fresh air supplies the fire with a fresh supply of oxygen. In essence, fires can generate their own winds, fanning their own flames. During the day, sunlight heats the ground and the warm air rises, allowing air currents to travel up sloped landscapes. At nightfall,the process is reversed. The ground cools and the air currents now travel down the slopes. Often fires will burn upslope during the day and down slope at night. Temperature acts upon the spread of wildland fires because the temperature of the fuel affects how quickly or slowly they will reach their ignition point and burn. Because fuels are also heated by solar radiation, fires in the shade will not burn as quickly as those in the direct path of sunlight. Humidity is a measure of the amount of moisture in the air. This moisture dampens the fuel, slowing the spread of flames. Because humidity is greater at night, fires will often burn less intensely at that time under normal circumstances, and therefore will not travel a great distance. The combination of wind, temperature, and humidity affects how fast wildland fires can spread. These combinations will change throughout the day and night, and the presence of fire will impact each factor, causing even greater variation. [1]

Topography of a landscape also affects the spread of wildland fire. Every wildland fire is different in the way that it behaves because of the changing combinations of so many factors, but topography remains constant and therefore allows for more constant predictions of how fire will behave in a specific area. An explanation of topography includes the shape of the landscape, its elevation, the slope direction and its exposure to sunlight, and the slope steepness (aspect).[1]

- The shape of the land determines how much sunlight or shade an area contains, affecting temperature and wind conditions. Certain fuels grow better under different conditions. In addition, if the landscape has barriers, including highways, boulders and rock slides, or bodies of water, the fire will not spread as quickly. [1]

- Elevation and slope direction affect the type and temperature of the fuel to the degree in which there are shaded and sunny areas. Elevation also impacts how much wind and moisture the area receives. [1]

- The amount of shade or sunlight, the temperature of an area, and moisture received by an area all determine the type of fuel available for wildland fires.[1]

- Slope steepness is important in that it contributes to how quickly the fire will reach the crest of the land form. When a fire begins at the bottom of a slope, the fuels located uphill are preheated by the rising air, helping them to easily catch fire when they come in contact with flames. Fires that begin uphill may deposit burning material that rolls downward, allowing more fires to begin downhill. [1]

3.2 Description of a fire

The parts of the fire to be controlled are the head, the flanks and the rear, as shown in the figure below.

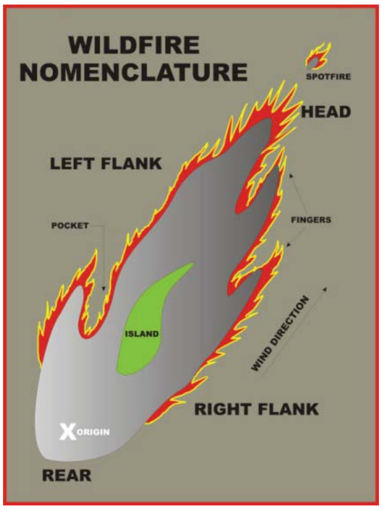


Figure 3.2: Fire nomenclature.

Fire is generally attacked from where it is easiest to escape. This may require attacking the fire from the head, the flanks, the rear, or any combination of the three. However, the primary concern is to attack the fire where it can be done safely. A good practice is to always pick an anchor point to start fighting the fire and to prevent the fire from outflanking. Fireline intensity (flame length) and rate of spread generally determine which part of the fire to attack, both in the initial attack and when suppressing large fires. Fire suppression limitations based on flame length provide guidance in order to make decisions as to which part of the fire to attack and whether to make a direct, parallel or indirect attack.

3.2.1 Parts of a fire

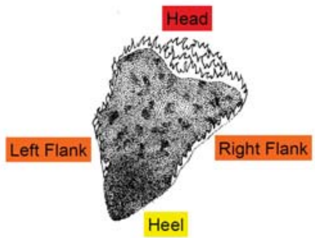


Figure 3.3: Parts of a fire

In a wildfire we can find many parts with different features. The point of origin or heel is located at the opposite side of the head of the fire, which is the point where the flames have begun to spread in the main direction of the wind. Climbing to the top of the bushfire, we can find the anchor points. These points are not only safe, but they also have an advantageous location in order to start the action of suppression and, above all, to create a barrier to fire spread from which to start constructing a fireline. The anchor point is used to minimize the chance of being flanked while the line is being constructed. Obviously the barriers can be natural or artificial like trails, roads, rivers, lakes, old burns or rocks. The position of the right and the left flanks of the wildfire can be determined by turning one's back to the anchor point. The head of the fire, which is often on the top, is the active area from where the flames spread. This zone is the most active in a wildfire and we can work on it only if the activity of the flames is feeble and permits to make a direct approach. Many times we can find, on the flank of the bushfire, several peninsulas of burned fuel where the flames are outflanked. These are called fingers. If there are fingers there are also zones called pockets, unburned indentations in the fire edge formed by fingers or slow burning areas. There are other particular zones in wildfires called islands, which are unburned. The spot fire is a zone outside the perimeter of the wildfire where a flame activity is present. This is attacked with direct techniques by air or ground teams. Near the head of the fire we can identify two areas. The first, known as fireline, is a part of a containment or control line that is scraped or dug to mineral soil. The second one is called backfire. This is an unburned area located between the fireline and the head of the fire, aimed at consuming the fuel in the path of a wildfire, and at changing the direction or force of the fire's convection column.

Strategy is an overall plan of action for firefighting which gives regard to the most efficient use of personnel and equipment in consideration of resource values threatened, fire behavior, legal constraints and objectives established for resource management. Tactics are the operational aspects of fire suppression, determining exactly where and how to build a control line and what other suppression measures are necessary to extinguish a fire. The ground personnel use different tactics based on the environment and other factors of the wildfire (in the next paragraph we are going to explain the Aerial Firefighting subject).

Direct attack "Any treatment applied directly to burning fuel such as wetting, smothering, or chemically quenching the fire or by physically separating the burning from unburned fuel." [3]

Direct attack is made directly on the fire's edge or perimeter. The flames may be knocked down by dirt or water and the fire edge is generally treated by a follow-up fireline. Or, a fireline is constructed close to the fire's edge and the fuel between the fireline and the fire is burned out or the fire is allowed to burn to the fireline. Direct attack generally works best on fires burning in light fuels or fuels with high moisture content burning under light wind conditions. Direct attack works well on low intensity fires (flame lengths less than 4 feet) which enable firefighters to work close to the fire. A major advantage of direct attack is firefighter safety. Firefighters can usually escape back into the burned area for a safety zone.

For all these types of strategy, there is a golden rule for decision making, namely that firefighter safety is the highest priority in fire suppression.

There are four main retardant deployment strategies to achieve a direct attack: flanking, tandem, pincer and envelopment action. These actions were originally developed by military tactics.

- Flanking Action: The engine moves along the line as fast as the fire is put out. The action starts at a anchor point and creates a fireline along one flank of the fire. [3]

- Tandem Action: Several resources move along the same line. The first crew creates the line and the second crew strengthens and secures the line. Engines can hop past other engines to give crews a rest at the lead. [3]

- Pincer Action: Both flanks are attacked at the same time. These engines could anchor into each other, if a road or other barrier was not available. [3]

- Envelopment Action: Fire is attacked at many places at the same time from several anchor points. Engines then move towards each other to connect the lines. This type of action needs to be well coordinated to avoid the fire escaping a section of unfinished line.[3]

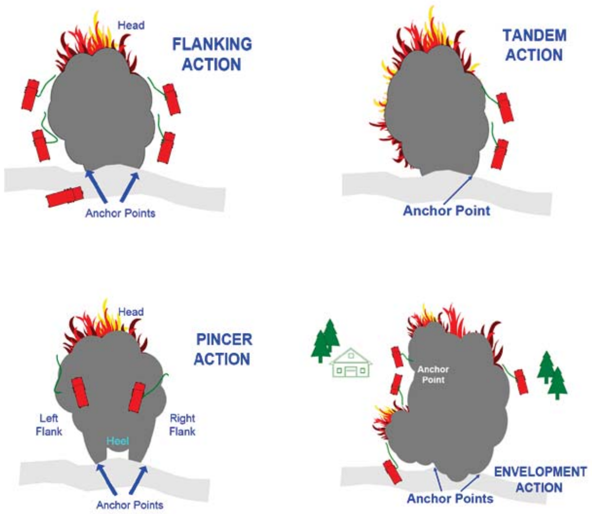


Figure 3.4: Types of tactics in direct attack.

Advantages

- Relatively safe tactic as firefighters can keep one foot in the black;[4]
- No additional (unnecessary) areas are burned;[4]
- Full advantage is taken of burned out areas;[4]
- Comes with less uncertainties than backfiring.[4]

Disadvantages

- Firefighters can be exposed to heat and smoke;[4]
- Lines can be long and irregular leading to more mop up and patrol. [4]

Parallel attack “Method of fire suppression in which fireline is constructed approximately parallel to, and just far enough from the fire edge to enable workers and equipment to work effectively, though the fireline may be shortened by cutting across unburned fingers.”[3]

Parallel attack is made by constructing a fireline parallel to, but further from, the fire edge than in a direct attack. This tactic may shorten fireline construction by cutting across unburned fingers. In most cases the fuel between the fireline and the fire edge is burned out in conjunction with fireline construction.

Advantages

- Reduced heat and smoke exposure;[4]
- Lines often straighter and shorter; [4]
- Line is placed to reduce chance of fire escape;[4]
- Line can be placed in lighter fuels; [4]
- Lines cut across fingers. [4]

Disadvantages

- No readily available safety zone;[4]
- Increases the area burned; [4]
- Doesn’t take advantage of already burned out areas. [4]

Figure 3.5: Parallel attack

Indirect attack "Method of suppression in which the control line is located some considerable distance away from the fire's active edge." [3]

Indirect attack is accomplished by building a fireline far away from the fire edge in order to create an unburned fuel area. It takes advantage of using natural and human-made barriers as fireline and allows a choice of timing for backfiring. An indirect attack is generally used on hot fires with high rates of spread where a direct attack is not possible. As in military strategy when fighting a stronger enemy, indirect attack is about selecting the best site on which to meet the fire and gain the greatest advantage.

Figure 3.6: Indirect attack scheme.

Advantages

- Can locate lines along natural or man-made barriers: topography, lakes, reservoirs, roads, etc.;[4]
- Reduced exposure to heat and smoke;[4]
- More time to construct fire lines and their location is not dictated by the fire;[4]
- Firelines can be constructed in lighter fuels.[4]

Disadvantages

- Increased area burned;[4]
- Can have safety hazards as crews are working some distance from main fire and may not be able to observe fire conditions;[4]

- Burning out can leave unburned islands;[4]
- Backfiring can be dangerous;[4]
- Doesn't take advantage of already burned out areas. [4]

Hot spotting "Checking the spread of fire at points of more rapid spread or special threat. It is usually the initial step in prompt control, with emphasis on first priorities." [3]

It usually occurs on the fingers of the fire. It is a dangerous technique and it is used to slow down or stop the rapid advance of fingers until a fireline is constructed.

3.3 Aerial firefighting tactics

3.3.1 Preface

The procedure in Aerial Firefighting operations is very similar to the military one.The water-bomber base receives the emergency call and immediately after the crew scrambles over the wildfire locations[5]. The intervention is not hit or miss. The fire-chief, in fact, decides the tactic to adopt depending on the situation. The basic methods used for extinguishing fires in forests and flatlands are three:

- the indirect attack;
- the direct attack;
- the parallel attack.

In the indirect attack, the fire is approached from the rear using the natural condition of the land to control the fire from the front; in the direct attack the fire is flanked and in the parallel attack the fire is approached with a mixture of methods in a narrow space.

Indirect attack The indirect attack is as often as not used for extended fires. The water-bombers used in this method are land-based retardant bombers. The technique of this modus operandi consists in dropping several retardant-bombers to create a straight line away from the main fire in order to create an artificial barrier for the head of bushfire. Furthermore, this raid is particularly efficient because it creates a synergic barrier between the artificial and natural obstructions so that the fire is easily extinguished.

Direct attack The direct attack is a strategy used both for extended fires and for small "hot spots". The water or retardant drops are usually poured directly on the fire or on the edge of a main fire. This type of aerial firefighting approach requires a great quantity of drops that will be streamed over and over again on the fire. For this reason the best aircraft used are the scoopers.

Parallel attack This type is a mixed strategy used for ragged edge fires. The distance between the drops and the edge of fire is very short. The advantage for this arrangement is the presence of light "fuels" between the barriers and the head of the fire. The drops, in fact, straighten the ragged edges of the fire and create a zone between the fire and the control line.

3.3.2 Tactics in firefighting

The employment of one method over another depends on many factors. There are a lot of types of bushfire and there are also the following factors to consider:

- Orographic conformation of the location;[6]
- Economic importance of the interested area;[6]
- Consistence and type of vegetation in the area; [6]
- Width and depth of the head of fire; [6]
- Local wind profile and propagation speed of the head of fire;[6]
- Availability (quality and quantity) of men and ground vehicles;[6]
- Availability near the wildfire zone of natural extinguishing liquid ready for use;[6]
- Practicability of paths alleging to the fire area;[6]
- Availability in quantity, type and tripping time of aircraft. [6]

According to the evaluation of these elements, which fluctuate and constantly influence each other, we can define the best way to take action.

If there was a little dimension bushfire in a wood area with tall trees it would be better to use a tactic of containment which is against the propagation of flames. For a little dimension bushfire with surface fuel the best way is to adopt a tactic of suppression in order to turn off fire directly. Wildfire with a medium or high size in an area with aerial fuel we can use a tactic of interdiction, with arrangement of fire barriers and dynamic contrast. The last action is used for fires with medium and wide spreads with a low vegetation type, the tactic of interposition consists in a direct attack and dynamic contrast. [6]

So we can explain the best techniques used in tackling bushfires based on three main points:

- Knowledge of wildfire characteristics and elements can influence the situation;[6]
- Quality of training of ground personnel in firefighting;[6]
- Continuous updating of influence items in the area . [6]

According to the valuation of these elements, which are naturally variable and evolving between them, we can define the best way to action.

If there was a little dimension bushfire in a wood area with tall trees it would be better to use a tactic of containment which is against the propagation of flames. For a little dimension bushfire with surface fuel the best way is to adopt a tactic of suppression in order to turn off fire directly. Wildfire with a medium or high size in an area with aerial fuel we can use a tactic of interdiction, with arrangement of fire barriers and dynamic contrast. The last action is used for fires with medium and wide spreads with a low vegetation type, the tactic of interposition consists in a direct attack and dynamic contrast. [6]

So we can explain better techniques used in bushfires based on three principal points:

- Knowledge of wildfire characteristics and elements can influence the situation;[6]
- Quality of training of ground personnel in firefighting;[6]
- Continuous updating of influence items in the area . [6]

We must adopt these techniques when possible and when the ratio between cost and predictable result is optimal. For more clarity, firefighting tactics are explained in the short list that follows.

Tactic of containment

- Direct attack on the flames with retardant drop from bombers and subsequently with water;[6]
- Mechanical or manual elimination with the ground teams of surface fuel in front of the head of fire;[6]
- Dynamic contrast from ground and air of the advancement front of flames with extinguishing liquid transported in the area or dropped by hely-tankers. [6]

Tactic of suppression

- Global attack of the flames with water or retardant dropping;[6]
- Dynamic contrast from ground with extinguishing liquid carried in the area by helicopter. [6]

Tactic of interdiction

- Attack from the air with retardant and water to the head of fire, with the purpose of stopping the forward speed;[6]
- Mechanical and manual elimination of short vegetation fuel with ground personnel in order to create a safety zone where to sprinkle retardant liquid;[6]
- Ground and air direct attack from the safety zone on the spot fire with extinguishing liquid transported in the area or dropped by helicopters. [6]

Tactic of interposition

- Attack of the head of fire with water or retardant dropping in order to reduce flames speed propagation;[6]
- Creation of a safety line free from fuel that allows ground team to attack with extinguishing liquid. [6]

3.3.3 Aerial firefighting techniques

We will now consider in depth some concepts used in Aerial Firefighting. The key concepts of Aerial Firefighting operations are summarized by the word SEE. This acronym means: Safe, Effective and Efficient. These three words sum up which aerial water bombing procedures should be followed during operations. This motto is vitally important to the crews of the air tankers when they go into action fighting a forest fire.

SAFE - Keeping yourself, your crew and the unit on the ground safe is the highest priority for firefighters in the air, and is more important than all the other measures. All efforts lead to the achievement of being effective as fast as possible.

EFFECTIVE - Effectiveness and success, though, are always subordinated to the safety of all procedures.

EFFICIENT- The personal achievement of the individual is thus less important than the safety and the effectiveness of all measures.

According to the pilots and crews of firefighting planes, tactics means "a series of tasks and operations, done to activate objectives".[7] We are going to explain the most important aerial procedures for air tankers. The wind is the main discriminating factor in determining the approaching run for a water drop. The water bomber always arrives on the location of the fire with a tailwind component. In the critical phase of a drop, the aircraft will have a headwind component. If during the extinguishing operations there is a variation in wind direction, the drop will consequently change.

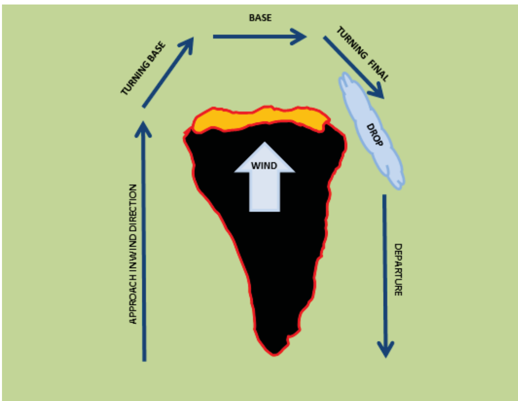


Figure 3.7: Water bomber standard run

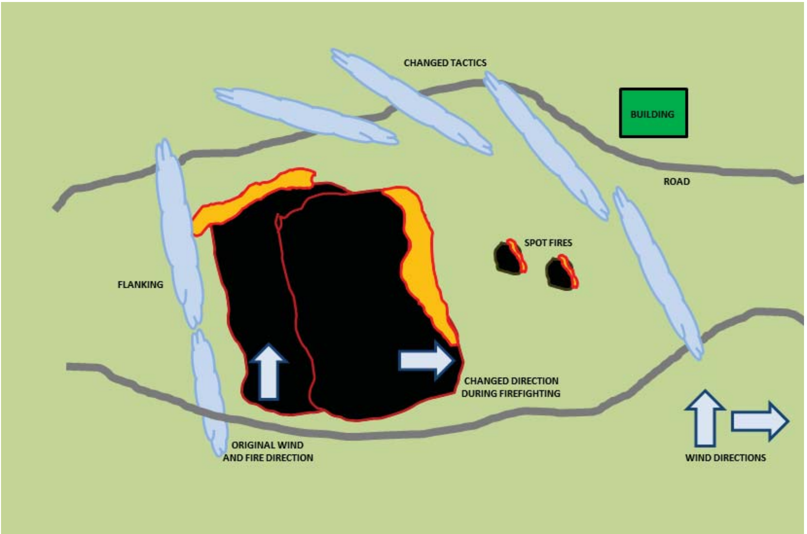


Figure 3.8: Changing tactics consequently a wind direction variation

Flanking "Flanking fire suppression" refers to an approach to the fire on one or both flanks. These extinguishing attacks are carried out in one direction in which the fire is spreading (wind direction) from a relatively inactive area or a tactically favorable and non-dangerous area (anchor point) in the back part of the fire. Flanking is a very effective tactic especially with a fast-moving fires. [7]

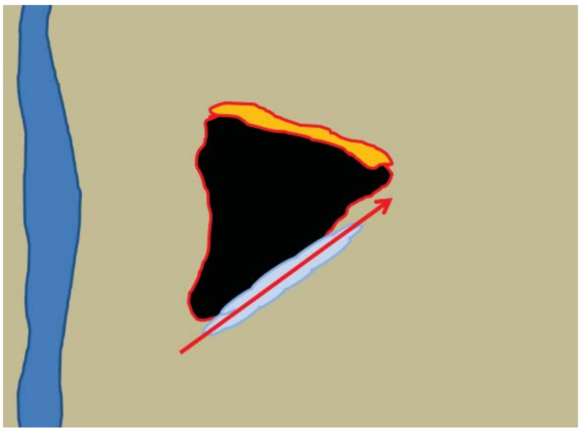


Figure 3.9: Flanking tactic.

Tandem Ahead Tandem refers to a combined tactic and procedure by two or more different air or ground units (for example air tanker and dozer), which carry out their firefighting activities immediately one after the other. "Tandem Ahead" is a forward-moving tactic (in the direction of fire), in which the appropriate measures are applied as nearly simultaneously as possible. A "Tandem Ahead" tactic applied by air tankers proves in practice to be especially helpful support to the ground crews, especially to the dozer crews who are setting up fire lines.[7]

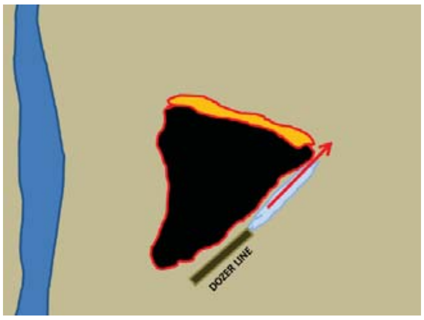


Figure 3.10: Tandem ahead.

Tandem Behind This tactic is a support action independent In time but carried out in close cooperation, for example, between two engine crews (teams with firefighting vehicles) and air tankers. It is carried out particularly to hold already applied fire lines and to protect buildings.[7]

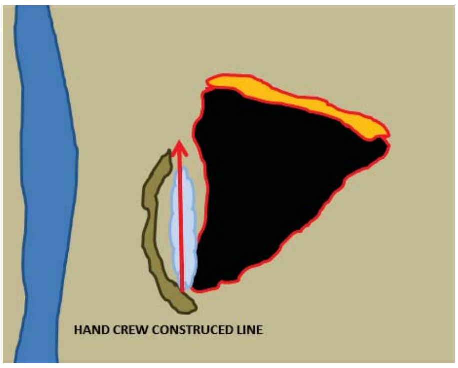


Figure 3.11: Tandem behind.

Hook Support tactics for ground units to hold already applied fire lines in flank areas of a fire.[7]

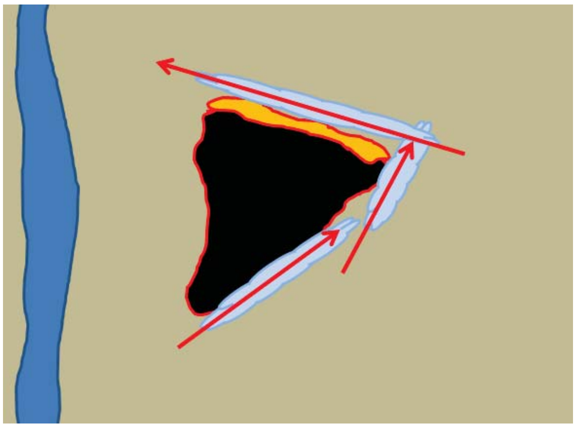


Figure 3.12: Hook.

Narrow Vee - Wide Vee An airtanker tactic in which a thin, only slightly spreading fire wall or a small-surface fire is stopped or extinguished by narrow or wide wedge-shaped drops of extinguishing or cooling materials. Such a quick attack to the head of the fire is, on the one hand, regarded as aggressive, and on the other hand as a timesaving method. Essential to its successful completion, however, is equally fast action by the ground crews in setting up fire lines or water lines. In this procedure, additional airtanker runs can be needed after an indefinite time.[7]

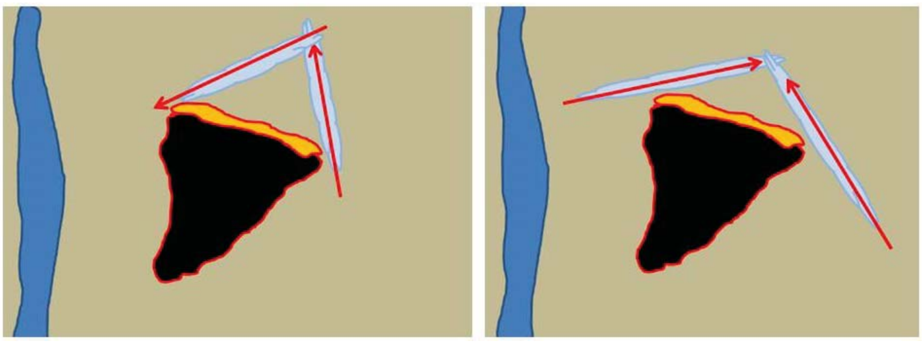


Figure 3.13: Narrow vee and wide vee.

Angle tie-in In the angle tie-in tactic, the work of the ground crews is supported by drops of extinguishing or cooling material, usually at right angles. Depending on the conditions at hand (for example, the direction in which the fire is spreading, natural barriers, etc.), airtanker drops can form a tactical "triangle" between the direction of the fire, natural barriers (such as roads or waterways), and retardant lines, which can then be worked on by ground crews (extinguished, burned out or mopped up). The angle tie-in tactic is an often-used cooperative method between air and ground units.[7]

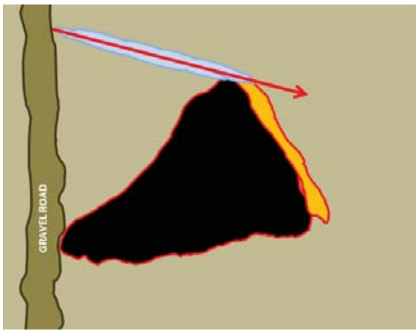


Figure 3.14: Angle tie-in.

Spot fire A spot fire is a fire outside the main fire area, perhaps ignited by flying sparks, that increases the danger of further spreading. Such a small fire is usually covered or extinguished by several drops of retardant or water from two directions. Drops from two opposed directions provides better cover of spot fires in hard-to-reach areas as well. [7]

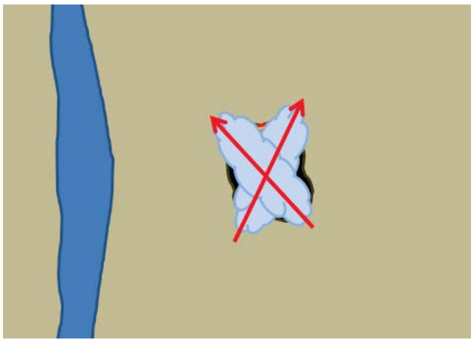


Figure 3.15: Spot fire.

Pre-treat Pre-treat is an advancing airtanker tactic in which fire lines are set up in anticipation of a spreading fire. Such fire lines are usually laid out by involving natural terrains barriers (such as rideges), to offer the ground crews standing ready in visible and protected areas an optimal starting point for control work. [7]

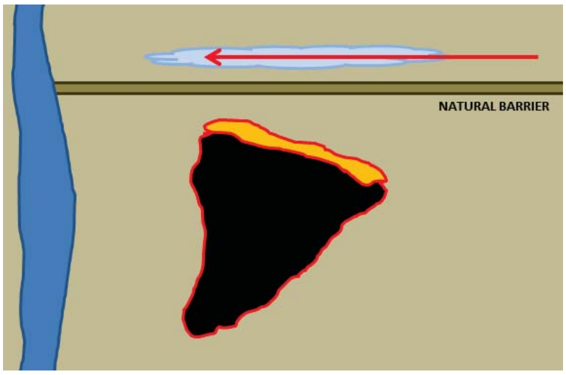


Figure 3.16: Pre-treat

Angle out An extended tactic of the "pre-treat", including further natural barriers (such as additional fire lines on canyon edges, besides the main fire line on a ridge. Such measures are carried out only in close cooperation with the ground crews and must be done appropriately early in tactical and technical terms.[7]

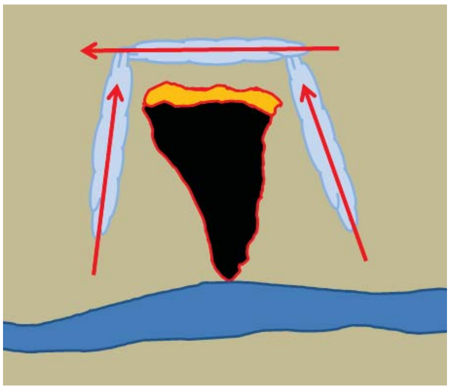


Figure 3.17: Angle out

Cooling convection current This situation-dependent tactic could be described as cooling spreading column of smoke and/or development of heat, in which airtanker drops are made specifically in the direction of spreading fire.[7]

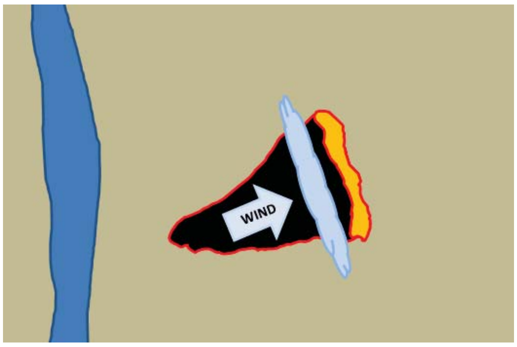


Figure 3.18: Cooling convection current.

Spot field cover A relatively new tactic in aerial firefighting is the spot field cover. It is used in forest fires that are typified by especially aggressive spreading and the initiation of spot fires. In spot field cover, several retardant lines are laid perpendicular to the fire's direction of spread and at varying intervals and distances. Thus even spot fires that are activated beyond one or more fire lines can be brought under control by limitation. A large number of airtankers would be needed simultaneously for spot field cover tactics.[7]

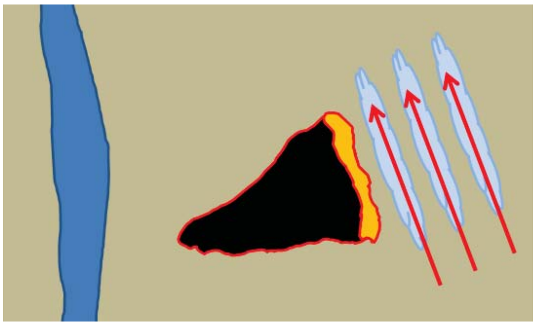


Figure 3.19: Spot field cover.

3.4 Aerial fighting materials

During firefighting operations, three types of chemical materials are used for missions. These are divided in:

- Long-term fire retardant;
- Short-term fire retardant;
- Water.

3.4.1 Fire retardants

Long-term fire retardants Fire retardants are the best choice to use in indirect attack because for their lasting properties on the ground. During the past aerial firefighters dropped a mixture of borate salts to fight wildfires. Although these chemicals were effective against the fires, they sterilized the soil and above all were toxic for the animals. The fire retardants used today in Aerial Firefighting are made of ammonium sulfate or ammonium polyphosphate with attapulgite clay thickener or diammonioum phosphate with guar gum derivative thickener (some water-dropping aircrafts carry tanks of guar gum derivative to thicken the water and reduce runoff). The fire retardants used today are more environmentally friendly than the borate salts used in the past because they also fertilize the plants which grow after the fire. Unfortunately if these retardants are dropped in to the water and exposed to the sunlight can be toxic for fishes. These type of retardants are Phos-Check D75-F, Phos-Check D75-R and Fire-Trol GTS-R. There are mixtures of diammonium sulphate, diammonium phosphate, monoammonium phosphate, gum thickeners, iron oxide colouring agent and preservatives. These are typically fertilizer salts which are mixed with water to ensure uniform dispersal. Even after the water has evaporated, the retardant remains effective until it is removed by rain or erosion. They form a combustion barrier after the evaporation of water carrier and their effectiveness depends on the amount of retardant per unit surface area. The ammonium salts chemically combined with cellulose only whit heated fuels, remove it effectively. The typical reddish orange pigmentation of retardants is due by the ferric oxide intentionally added to the retardant to mark where they have been dropped.[8]

Short-term retardants (foams) The firefighting foam is used for the fire suppression. The purpose is to cool the fire and to coat the fuel, preventing its contact with oxygen, resulting in suppression of combustion. The surfactants used must produce foam in concentration of less than 1%. Other components of fire-retardant foams are organic solvents, foam stabilizers and corrosion inhibitors. Foams are identified by their expansions properties: low-expansions foams have an expansion rate less than 20 times, medium-expansions foams have an expansion ratio between 20 and 200 and high-expansions foams have an expansion ratio over 200. In wildfire cases the best foams used are low-expansion type (AFFF)(nota), which have a low viscosity, mobile and are able to quickly cover large areas. Unlike the long-term retardants which remain effective after the water has evaporated, short-term fire retardants depend on the water they contain to retard or suppress the fire. The foams used are Ansul Silv-Ex, Angus ForExpanS, Fire Quench, 3M firebreak and Phos-Check WD-881, and all contain surfactants and wetting agents which increase the ability of the drained water to penetrate fuels thus reducing their abilities to ignite. Fuels are insulated from heat and the air contact is also reduced. These retardants loose their effectiveness once the water has evaporated or drained from them. Foams are typically applied in the field at concentrations between 0.1% and 1.0%. These foams aid fire suppression and can prevent reignition. Wildland fire foam is effective for several hours and is often used for supporting ground firefighters.[8]

3.4.2 Water

Water Although water is easily available, it's also the least effective means of fighting a fire from the air. It can be used in direct support, especially if the supply is plentiful and the ground firefighters are nearby to follow up action.[5]

Chapter 4

AIRCRAFT USED FOR FIREFIGHTING PURPOSES

There are many types of firefighting aircraft. We can divide them into:

- Fixed-wing;
- Rotary-wing.

These two types play two different roles and as such they are used in two different types of wildfire attacks. The first is used for wide wildfire attacks in order to help the ground extinguishing operations. The second is used to make focused and initial attacks or to support the ground teams. Fixed-wing aircraft are classified by their missions, and they are: water bombers and supporting aircraft. Water bombers are, in turn, classified by payload classes and number of engines. An example of this type of classification is the SEAT (Single Engine Air Tanker). This converted aircraft is used for agricultural purposes. Supporting aircraft, on the other hand, are classified by the role they play in firefighting missions.

4.1 Fixed-wing

4.1.1 Air tactical aircraft

We can list three types of air tactical aircraft (excluding Water Bombers):

- Command planes;
- Lead planes;
- Jump planes.

4.1.1.1 Command planes

Firefighting must be led and directed – this is not only the practice in the USA, but in almost all the countries of the world. And what applies to leading the action of ground crews is not essentially different in fighting forest and surface fires from the air.[7]

The principal mission of these types of actors in the operation theatre is to coordinate air attacks from air tankers, helicopters, jump planes (a practice used only in the USA) and transport planes. All these planes operate in close cooperation with ground forces or with liaison personnel used for directing extinguishing operations. The mission of spotter airplanes is so simple, according to tactical and informal requirements. They fly over the scene in circles in order to take the right tactical decision for the firefighting attack. Command planes are usually mid-sized passenger or transport planes equipped with the necessary instruments for directing the action. Helicopters are rarely used for this purpose, due to their speed, flying characteristics and their size. They are usually unsuitable or only partially suitable for this task. During the mission, the "air commander" is supported by a tactical operator for observations, radio communications and documentations. Sometimes other leadership personnel or other figures in charge can help the air-commander in the process of decision making.

The tactical concept of air attack operations is dominant in the USA. In Europe and other countries the function of the air commander is relatively unknown in this form. Aircraft used in fighting forest and surface fires are generally directed there from the ground. An example of this is the "Officer Aero" (flight leading officer) of the French firefighters. Years ago, after negative experiences with leading the action on ground and air units under a joint command, the French introduced the position of "Officer Aero" so as to improve the qualification and safety of the air attack by separating the two functions, and at the same time unburdening the chief action commander. The Officer aero fulfills a ground-bound function on the principle that the action leadership is directly divided. In larger actions, the Officer Aero usually has an aircraft (more often than not a helicopter) at his disposal for information and coordination flights over the area.[7]

4.1.1.2 Lead planes

This role is very important in the circumstances where the pilots of firefighting airplanes are not so familiar with the fire location. Lead planes act as "follow me" for the water bombers: they lead them from the airport where they are based to the air attack area. In the USA lead planes are critical because the crew of the water bombers can fly all around the country where the fire risk is higher, according to necessity. These roles could be important in the European situation, where severe fires are fought by joint forces from different countries.

They are usually fast and nimble propeller planes meets the firefighter planes at the fire airbase and conduct them to the action area. Once arriving at the action area, the planes are assigned either to a holding orbit at first, or directly to a drop orbit for retardant. After the drop, the airtankers may be led back to the fire airbase by the lead plane. Being led directly to the action and drop site by a lead plane has proved to be tactically the fastest and surest method in aerial firefighting.[7]

4.1.1.3 Transport aircraft for smokejumpers

Jump planes are used only in USA firefighting tactics. In Europe this is an unknown methodology and it is not used. They are used in Russia to some extent, due to the vastness of its national territory. Smokejumpers are special firefighting ground teams that are transported by airplane and parachuted over or near a wildfire; they land often very close to the heart of the fire. They are employed in those situations where the ground teams can't reach the fire location easily or in a reasonable time.

Their action is technically and tactically most highly prepared, calculated and basically safe. They usually land in a safe surrounding area of a forest or surface fire and sometimes must walk long distances to reach the actual fire.[7]

These special forces of firefighters generally stay in the area only 48 hours until the ground forces arrive and take over the firefighting work. Jump planes are cargo aircraft used to carry a maximum of twenty jumpers with all their equipment. In these types of operation, spotter aircraft assume a most important role in the safety and organization of the action. Two command planes can be present in the same airspace in order to coordinate and be responsible for the safety of the jump.

4.1.2 Water bombers

In this section we are going to explain the differences between the water bombers typically used in firefighting action, as categorized by their payload.

AIRTANKERS CLASSIFICATION			
Type I: 3000 Minimum Gallon Capacity			
Aircraft	Maximum Gallons	Cruise Speed (knots)	Number of Doors
C130 (MAFFS)	3000	250	Pressurized System
P3-A	3000	240	Constant Flow
DC-7	3000	235	6-8
Type II: 1800-2999 Minimum Gallon Capacity			
DC-6	2450	215	8
P2-V9	2450	184	6
Type III: 800 - 1799 Minimum Gallon Capacity			
CL-215 (Scooper)	1400 (water)	160	2 (foam capable)
CL-415 (Scooper)	1600 (water)	180	4 (foam capable)
S2 Tracker	800	180	4
S2 Turbine Tracker	1200	230	Constant Flow
Air Tractor AT-802F	800	170	Constant Flow
Type IV: Less than 800 Gallons			
Air Tractor AT-802/602	600-799	160 mph	1 (in-line or horizontal)
Turbine Thrush	400-770	140 mph	1 (in-line or horizontal)
Turbine Dromader	500	140 mph	1 (in-line or horizontal)
Piston Dromader	500	115 mph	1 (in-line or horizontal)

Table 4.1: ICS Airtanker Classification[9]

In relation to their capacity, Water Bombers are divided as follows:

- Very large airtanker (VLAT)[1];
- Type I – The "large airtankers";
- Type II – The small "large airtankers";
- Type III – The "medium airtankers";
- Type IV – The "small airtankers".

4.1.2.1 Very large airtankers

This category was born for a research study promoted by the U.S. Department of the Interior after the accidents incurred by two airtankers in 2002[2] during firefighting operations. The study was an official "Request for information on next-gen airtankers". At the end of this study, two companies developed two water bombers by adapting aircraft used in the civil field, namely the McDonnell Douglas DC10 and the Boeing 747. These super Water Bombers have a very high payload performance, and as such they are able to create longer and thicker firelines on the ground. The two companies that developed the project were the Evergreen International Aviation and the 10 Tanker Air Carrier. The research was very expensive and the alterations concerned the installation of internal tanks, associated systems and the support structure for the aerial dispersal of liquids. Both these airplanes must return to the airbase after dropping because they need to refill their tanks. The daily drops are limited by the turn-around time of the aircraft.

4.1.2.2 Type I – The "large airtanker"

In the ICS Classification, airplanes are categorized by their capability to carry loads. Type I is the largest. Outside the US, type I aircrafts are called "Large air tankers" or "Heavy air tankers". The majority of these are often reconverted four engine aircrafts, used mostly for water bombing, like the DC-7 or the P3-A. The others are military transport aircrafts with a dropping system called MAFFS. The MAFFS is an airborne water dropping module, mostly found in C130A aircrafts. The Modular Airborne Fire Fighting System is a self-contained

[1] VLAT are not considered and classified yet in ICS system.

[2] A C130A and a P4Y-2 for structural failure due to age limit of the lifecycle.

unit used for aerial firefighting which allows transport aircrafts to be used as air tankers against wildfires. This allows the U.S. Forest Service (USFS) to utilize military aircrafts from the Air National Guard and Air Force Reserve to serve as an emergency backup resource to the civilian air tanker fleet. In this section we can find an oversized firefighter like the Martin Mars, a big amphibious aircraft, of which there are only two in the world. Most Type I aircraft were retired from service in May 2004 for aging and safety problems.

4.1.2.3 Type II – The small "large airtanker"

This category of airtankers has a lower tank capacity which ranges from 6800 to 11300 liters.

In American aerial firefighting, the Type II airtankers represent the largest numbers of firefighting planes. Among the best known tankers in this category are the Douglas DC-6, Douglas DC-4, Lockheed SP2H, and Lockheed P2V Neptune. The firefighting planes of this size were also mainly taken over from the military and converted, rebuilt or extended for use in fighting forest and surface fires. The Type II airtankers were also restricted from forest and surface firefighting as of April 2004 for reasons of safety. At this time only a few planes of this category are in use. They had to undergo an especially intensive and detailed safety test in advance.[7]

4.1.2.4 Type III – The "medium airtankers"

Type III airtankers are the medium-size firefighting planes (medium or standard air-tankers). The planes carry retardant tanks with a capacity of 2270 to 6800 liters.[7]

After April 2004 this type of firefighting aircraft gained an important role in wildfire extinguishing activity, because several Type I Airtankers, the most often-used plane in America, was retired. In order to replace the water capacity of large aircraft, currently there is a need for more medium bombers, if we are to maintain pre-2004 efficiency levels.

Among the best known firefighting planes of this class are also the American Douglas A-26 Invader, an ex U.S. Army twin-engined bomber, the Fokker F-27, used in Canada as well as in special cases in the USA, and the AT-802 and AT-802 Fire Boss, further developments of former agricultural planes that are taking on an increasingly significant tactical role in forest and surface firefighting in the USA as well as in Europe and many non-European countries. Also ranked among the Type III airtankers are most of the amphibian firefighting planes.[7]

4.1.2.5 Type IV – The "small airtanker"

The Type IV or SEAT (Single Engine Air Tankers) are the smallest firefighting planes, with a 380 to 2270 liters payload range. The best-known aircraft in this category are agricultural planes that were rebuilt to fight forest and surface fires.

At this time, Type IV airtankers see service in USA only in rare cases and in initial actions against small surface fires. These planes are used much more often in Canada, in the Mediterranean countries and in numerous East European Countries. The number of Air Tractors used in forest and surface firefighting there has increased greatly in recent years.[7]

4.2 Helicopters

Rotary-wing aircraft represent an additional resource in Aerial Firefighting. Outnumbering tankers in fleets around the world, they play an important role in firefighting. In many countries they are the only resource to fight wildfires, being used like water bombers in order to create safe lines for the benefit of ground teams. In countries with a well-known wildfire problem, rotary-wing aircraft work in synergy with fixed-wing aircraft in order to face fires. Besides pure firefighting, they are also used for special missions: to transport equipment, materials or ground teams close to the attack zone. They are also used as observation aircrafts or rescue aircrafts. Tactics for helicopters are the same as for fixed-wing water bombers, with the difference that water bombers are faster but less maneuverable. Helicopters are used in missions where precision is required in terms of time and space, although they are able to carry a smaller water payload. A classification exists for helicopters too. They are divided into ICS Type I, II and III. The basic classification of rotary-wing aircrafts is by type of mission, as follows:

- Fire Helicopters;
- Helitankers;
- Helitack Helicopters.

4.2.1 Size classification

According to the rules of the American Incident Command System (ICS), firefighting helicopters (fire helicopters, helitankers and helitack) are divided in to size groups I, II and III. The main criterion is the amount of water, retardant or foam the can carry, plus the maximum load limit and the available passenger seats.[7]

The chart shows the three classes of helicopter, from the biggest (Type I) to the smallest helicopter (type III).

Typification of Helicopters (USA) according to Incident Command System (ICS)

Type	Amount of liquid carried		Load limit	Passenger Seats
	Gallons	Liters	lb/kg	
I	700 & more	ca. 2650 & more	5000/ca. 2268	15 & more
II	300 to 699	ca. 1135-2650	2500/ca. 1134	9 to 14
III	100 to 299	ca. 378-1135	1200/ca. 544	4 to 8

Table 4.2: Helicopters classification.[7]

Worldwide, Type II and III helicopters are commonly used to fight forest and surface fires. Type I helicopters are rarely used because of their small number.

4.2.2 Mission classification

4.2.2.1 Fire helicopters

This category of helicopters includes all the machines provided with an external tank. They are often helicopters used for various purposes, but in emergencies they are transformed for a firefighting mission using a cargo hook coupled with a load container, which is controlled by a hydraulic or radio remote actuator for the dropping phase. Flexible load tanks are called "Bambi Buckets". They are filled by the pilot in any suitable body of water near the fire location. Bambi Buckets are produced in different sizes in order to meet stakeholders' needs. Some of those are developed only for specific helicopter models. This tank is used to drop water or retardant on specific fire points with accurate shots and with a bigger precision than aircraft. The full load can be discharged in a single drop or sprayed all over a specific surface of land.

Another use of special rigid Bambi Buckets is to supply water to ground and engine crews in isolated terrain-limited hard to reach action areas; they can be delivered to scenes of action by helicopters as outside loads.[7]

Another type of fixed tank used in firefighting is tanks hooked to the helicopter's underbelly. These are similar to the flexible ones but they have a rigid body filled with water or retardant. This type of tank is able to make scooping actions like the first ones.

Figure 4.1: Bambi bucket operations

4.2.2.2 Helitanker

The modern generation of helicopters used in firefighting is called helitankers.

These are rotary-wing aircrafts equipped with a rigidly built-in tanks, mounted under the cabin floor between the skids. [7]

These fixed tanks come in various dimensions, depending on the type of vehicle they will be mounted on. This application grants them a lot of positive feedback: their most efficient use is to fight local spot fires, whereas it is not so appropriate to use them to fight big fires during large-scale attacks. There are some design problems due to the low clearance under the helicopter fuselage. This creates some problems in the landing phase. The cargo hook is unusable if this equipment is installed. This turns it into a one-mission vehicle, removing the possibility to use it for transport purposes. The only way to refill the tanks is to return to a zone with a specialized ground crew. With this installation it is not possible to make a scooping maneuver. Only the Sikorsky S-64 Skycrane, equipped with a flexible and a rigid snorkel, can refill the tanks while the helicopter is in hovering position or in movement.

Figure 4.2: Sikorsky S64-F Skycrane

4.2.2.3 Helitack

Helitack helicopters have two functions: transporting special trained ground crews and the equipment and materials to the scene. Type II or Type III helicopters are usually used for this mission but sometimes they can be equipped with the external Bambi Bucket when the transport mission is over. Helitack passengers are special units who are transported to the scene of the fire. During the initial attack they are roped down or grounded in the red zone because the traditional equipment cannot take them to the fire location in the required time. After that, helitack can bring the ground personnel or the material and equipment that will be used to face the fire to the fire location. They can be used as firefighting helicopters if strictly necessary, but for tactical reasons they are not the best choice for firefighting missions.

Chapter 5

FIREFIGHTING ORGANIZATIONS: MAIN CASE STUDIES IN THE WORLD

The organization of firefighting is not the same around the world; it changes from country to country. Every nation has got many different managing models for civil security. The purpose of this section will be to explain the models of organization of these countries:

- USA;
- Canada;
- Australia;
- France.

We are going to analyze every single aspect of the organization of firefighting in these countries, in order to determine what the key strength and weakness in every model are, so as to reconsider the Italian case and export the key strengths we have found to our country, if necessary.

We have decided to examine these countries because they present very deep interpretative differences in Aerial Firefighting. In the Firefighting field, it is common practice to share information between countries in order to improve operational safety, efficiency and effectiveness of aerial fire suppression.

5.1 Incident command system

ICS is a worldwide system used in case of emergencies, adopted in order to have the same operative standards. It was developed during a wildfire suppression in California during the 1970s, after the dramatic outcome of a series of fires that occurred near the urban area. The analysis of events demonstrated some faults in incident management.

Weakness in incident management were often due to:

- Lack of accountability, including unclear chains of command and supervision;[10]
- Poor communication due to both inefficient uses of available communications systems and conflicting codes and terminology;[10]
- Lack of and orderly, systematic planning process;[10]
- No predefined methods to integrate inter-agency requirements into the management structure and planning process effectively;[10]
- Freelancing by individuals with specialized skills during an incident without coordination with other first responders;[10]
- Lack of knowledge with common terminology during an incident. [10]

Incident Command System is definitively a tool to utilize in the event of incidents that can hurt people or damage properties or the environment, for example wildfires, terrorist events, planned events (concerts, parades), SAR missions or natural disasters. The approach of the ICS changes in order of incident's gravity, complexity and type. It is based on key factors such as changeability and scalability. It can grow or shrink in order to comply with the changing needs of any incidents. The structure is based on the "first-on-scene" concept, which allows the first responder to an incident scene to be in charge of command until the incident has not been solved. The resolver stays in charge until a more qualified person arrives on the scene.

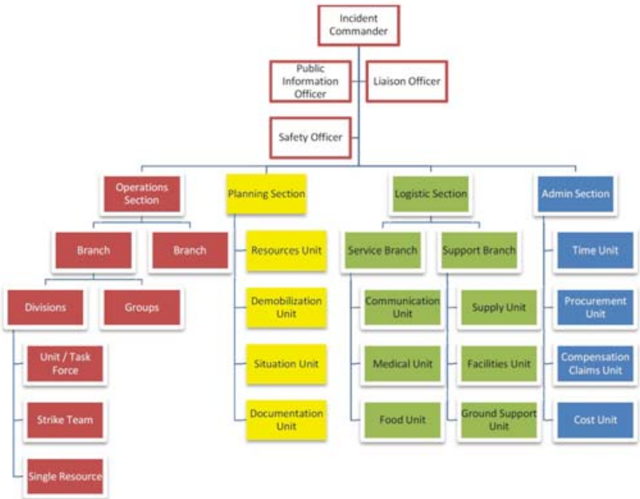


Figure 5.1: ICS organization tree

In this system we have five major management roles:

- Incident Commander: has overall responsibility, sets objectives, strategies and priorities;
- Operations Section: has the task to operate at the incident location, setting the tactical objectives, conducting the plan and directing the resources;
- Planning Section: prepares the Incident Action Plan, recording the incident documentation and resources status, collects and evaluates information;
- Logistic Section: has the duty to provide services needed by the Incident Staff in order to accomplish common objectives;
- Finance/Administration Section: monitors costs and provides accounting and supplies.

5.2 United States of America

5.2.1 Firefighting organization

The USA is the birthplace of Aerial Firefighting. American Aerial Firefighting is controlled by several bodies that contribute to fire suppression. Their responsibilities vary according to the extent of the wildfire: small fires are managed at a local level, whereas larger ones are managed at a national level. The main agency is called National Interagency Coordination Center and is located on the west coast of the United States at Boise, Idaho.

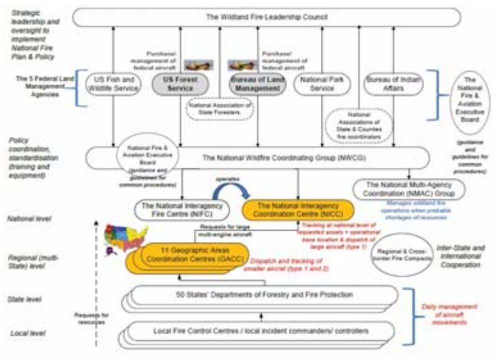


Figure 5.2: USA organizational diagram

The complexity of the process will be described by reviewing the four main actors in the American firefighting system.

At the top of organization is the council, which has the power to legislate.

Wildland Fire Leadership Council The Wildland Fire Leadership Council is an intergovernmental committee of Federal, state, tribal, county and municipal government officials convened by the Secretaries of the Interior, Agriculture, and Homeland Security dedicated to consistent implementation of wildland fire policies, goals and management activities.

The Council provides strategic oversight to ensure policy coordination, accountability and effective implementation of Federal Wildland Fire Management Policy and related long-term strategies to address wildfire preparedness and suppression, hazardous fuels reduction, landscape restoration and rehabilitation of the Nation's wildlands and assistance to communities.

The Council, through its members and pursuant to relevant statutory authority, works strategically to develop, review, update and monitor implementation of:[11]

- Federal Wildland Fire Management Policy;[11]
- Federal Line assistance, Management and Enhancement Act of 2009 (FLAME Act);[11]
- A Cohesive Wildfire Management Strategy (2009 Quadrennial Fire Review);[11]
- 10-Year Comprehensive Strategy (August 2001) & Implementation Plan (December 2006);[11]
- Other policies, procedures and program management activities designed to protect communities and natural resources from wildfires, reduce hazardous fuels, restore fire-adapted ecosystems, and assist communities in their efforts to reduce loss wildfires. [11]

The council is made up of nine members, three are Federal officials and the other seven are non-Federal members. The Federal ones are: U.S. Department of Agriculture, U.S. Department of the Interior and U.S. Department of Homeland Security. Responsibility for chairing the Council will alternate between the Department of the Interior and Agriculture annualy.[11]

In the middle there is the governmental authority, which sets the coordination and standardization of policies, implementing rules of firefighting matter. Its aim is to achieve overall standardization of procedures and resources in the American firefighting system, so as to achieve the highest standards in the world in wildfire management.

National Wildfire Coordinating Group The purpose of NWCG is to coordinate programs of the participating wildfire management agencies so as to avoid wasteful duplication and to provide a means of constructively working together. Its goal is to provide more effective execution of each agency's fire management program. The group provides a formalized system to agree upon standards of training, equipment, qualifications and other operational functions. Agreed upon policies, standards and procedures are implemented directly through regular agency channels.[12]

The National Wildfire Coordinating Group is made up of the USDA Forest Service; four departments from the Interior Agency (Bureau of Land Management, National Park Service, Bureau of Indian Affairs and the Fish and Wildlife service); and State Forestry agencies through the National Association of State Foresters.

At the bottom we have the operative part of the American Wildfire firefighting system. The organization is composed by three tiers which follow a saturation logic, starting from local level up to national level.

- TIER 3 - Local control: A wildfire is initially managed by the local agency (usually Counties) that is responsible for fire protection in a particular area. The agency activates every resources in order to face the fire. They usually are ground crews, engines, helicopters, smokejumpers and Type III and Type II airtankers, employed in order to start the suppression mission. Sometimes agencies work together sharing personnel and machines in order to contain new fires after the initial response.
- TIER 2 - Geographic Area Coordination Centers: When local equipment and personnel are insufficient to fight the flames and the wildfire is set to increase its size, a new level of fire coordination is required. The middle level is represented by the Geographic Area Coordination Centers (GACC). The United States is divided in 11 geographic areas. A GACC is located in each of these areas. GACC are:
  - Alaska Interagency Coordination Center;
  - Northwest Coordination Center;
  - California Northern Operations Coordination Center;
  - California Southern Operations Coordination Center;
  - Northern Rockies Coordination Center;
  - Eastern Great Basin Coordination Center;
  - Western Great Basin Coordination Center;
  - Southwest Coordination Center;
  - Rocky Mountain Coordination Center;
  - Eastern Area Coordination Center;
  - Southern Area Coordination Center.

Figure 5.3: GACC location in USA

Every GACC provides a Geographic Area Coordinating Group made up of fire directors from Federal and State land management agencies. They collaborate not only for wildfires but for every type of natural disaster or other emergency incidents.

The primary mission of the GACC is to serve Federal and State Wildland fire agencies through logistical coordination and mobilization resources (people, aircraft, ground equipment) throughout the geographical area, and with others areas, as necessary. This is generally done through coordinating the movement of resources between the many Dispatchers Centers present in the area[13]. GACC is responsible also for Predictive Services, Intelligence and for several centers' Fire Information. Predictive Service is composed by meteorologists who analyze and monitor data from weather, fuel conditions, conduct briefings and produce fire danger forecast, while the Intelligence Section mission is to collect and disseminate wild land fire and prescribed fire activity information, monitoring the resources and maintaining and collecting wild land fire records. The Predictive and Intelligence Sections work collaboratively producing Fire weather and Fire Danger Outlooks. The GACC have not initial-attack dispatch responsibilities.

- TIER 1 - National Interagency Fire Center: This is the last level of coordination, the National part, when the resources of the GACC and Local Agency are not enough and have exceeded their internal capability to fill request as a result of supporting multiple incidents, the request for personnel , aircraft, equipment and supplies are routed to NICC.[14]The monitoring of the operations is the primary responsibility of local incident commanders, under the control of the relevant Geographic Are Coordination Centre. The role of the NICC (the central agent) is limited to the central tracking of resources requested by lower levels (regional, state, or local levels) as well as the operational base location and dispatch of large multi-engine aircraft (Type I aircraft).[15] The other branch inside the NIFC is the National Multi-Agency Coordination Group. It is used to allocate and prioritize personnel and equipment if several simultaneous national emergencies are straining the system.

5.2.2 Aviation operations

In the United States the resources for Aerial Firefighting come from both private contractors and federal agencies. The US federal land management agencies are: US Forest Service (USFS), US Bureau of Land Management (BLM), US National Parks Service, Bureau of Indian Affairs and the Fish and Wildlife Service. They are all responsible for fire suppression on federal lands and works cooperatively through the National Interagency Fire Centre (NIFC).[16]

The administration for fire aviation contracts are only made by two of these agencies. These are USFS and BLM, which have different duties. The first one deals contract for large multi-engine air tanker fleets, whereas BLM only for the single engine air tanker fleet (SEAT).

The US Forest Service contracts at regional level whereas the Bureau of Land Management contracting process is centrally managed at the Department of Interior.[15]

US Forest Service, US Department of Agriculture Aviation is the most expensive component of the USFS fire suppression operations because most firefighting fleets are contracted, spending 98% of the total budget. For a uniform coverage and availability of larger aircraft during the danger period, USFS prefer to have the majority of the aircraft under an Exclusive Use contract. Nowadays the "Contract When Needed" system is considered obsolete and ineffective because the aircraft (in particular Type I helicopters) may be contracted by other companies (for example in the oil industry), and therefore they might not be available when needed. In order to have a full aircraft availability for the fire season, the USFS reaches a middle term contract deal with aircraft owners. This type of contract typically includes some key points such as:

- Availability of 90 or 120 days per annum;
- Must be able to move from state to state to support fire suppression operations nationwide;
- Contracts are for 1 year with 2 for "+1 year" options for a maximum of 3 years.

  The USFS contracts pilots as well who must meet minimum requirements and whose performances are monitored during the firefighting season.

  USFS contracts spell out the minimum aircraft requirements and minimum pilot standards and any special requirements expected by the USFS.[16]

  There are also contracted full time aircraft maintenance personnel. These personnel undertake site inspections of contract operators and audits of their records.[16]

US Bureau of Land Management, Federal Department of Interior Each region within the four Bureaus responsible for wildland fire suppression bids for their aircraft service requirements for the upcoming period. The Department of Interior's Acquisition Section manages contractual processes and acts as a broker for what the regions get.[16]

Contracts are awarded on the basis of:

- Contractor experience;
- Contractor past performance;
- Aircraft capability;

- Price.[16]

  The Bureau of Land Management usually contracts, each year, 90 SEATs with a contract duration that ranges from 60 to 90 days per annum.

There are two bodies in the US that supply their own Aerial Firefighting fleet. These are the California Department for Forestry and Fire Protection and the LA County Fire Department. The first one manages its fire and aviation responsibilities through its Fire Protection Division, while the LA County has all aircrafts bought or kept under a leasehold arrangement, pending full purchase by the County Fire Department.

5.2.2.1 Aerial resource management

Aerial deployment is managed at a regional or state level by the local fire control centers. If federal level resources are used, it is largely responsibility of the local or Incident Controller to manage aerial resources and to demonstrate effective use during an incident.[16] The request has been migrated from a paper-based system to an improved computer based system called ROSS (Resource Ordering and Status System). The aim was to effectively and efficiently monitor firefighting assets, at national as well as local level, during a fire.[16]

Federal resources (large multi-engine aircraft or Type I helicopters) must be requested from the National Interagency Coordination Centre by Regional Coordination Centers. NICC determines the location of regional resources as multi engine bombers (USFS) and SEAT (BLM) across the US federal agencies. The dispatch of resources at a higher level is helped by scientific forecast data, such as changes in fire danger indices, current incidents and seasonal risk profiles. Regional bases and state level offices coordinate all the medium and small resources independently from NICC. The reasons for this appear to relate to the fact that the effective range of large aircraft is larger than state boundaries and therefore they have significant capability to be dispatched to incidents outside regional responsibilities. The level of coordination in the management of these assets is largely limited to tracking their location by NIFC and coordination of relocations in response to changing risk profiles.[16] Coordination at every level is helped by electronic tools that permit to track and monitor the aircraft activity, but this is not the only factor that influences the decision of deployment. Local knowledge and experience help skilled staff make decisions regarding resource deployment, making use of available information and seasonal trends. This fact encourages local agencies to locate resources following local knowledge and experience, in order to hold the key to effective and efficient use of aerial suppression resources.[16]

The only weakness of this system is the mix of coordinating bodies that can slow the logistic decisions.

ROSS The ROSS application is a Java®-based software application, intended to automate the business processes associated with resource status and resource ordering by wildland agency dispatch centers.

The ROSS application does not replace decision-making. It facilitates the collation of critical resource information so dispatchers and managers can make better decisions. ROSS benefits the general public in terms of improving incident response times and cost effectiveness.

As a universal application that ties to a centrally located data repository, ROSS will offer real-time reporting capability on a nationwide basis.

ROSS data will offer managers and intelligence/predictive services specialists the ability to easily produce extensive reports for detailed statistical analysis.[17]

5.2.3 Financial arrangements

Aircraft resources at federal level are financed in two different ways: centrally through the Department of Interior budget, for BLM resources, and through the Forest Service 'regions' for the USFS.

State Departments of forestry receive federal assistance for wildland fire management and suppression. The federal government also has more than a dozen forestry assistance programmes, including rural/forest fire fighting programmes and numerous programmes to support state and private forestlands. Wildfires fighting also benefits from financing of disaster response schemes.

With regard to sharing the costs of fighting wildland fires between federal and non-federal entities, master agreements are usually signed in the framework of each state. These documents specify how cost are to be shared for each fire that burn across multiple jurisdictions. Cost Sharing methods generally include surface area burned, cost distribution, or variations of these two methods.[15]

5.3 Canada

5.3.1 Firefighting organization

Canada is one of the most active country in wildfires fighting. The severe climate conditions and the topographical characteristics make this nation a unique example in firefighting. The Canadian organization has decentralized responsibilities: each region or province is independent in wildfire management.

Provinces are connected with a purpose-built intermediary body[15] called Canadian Interagency Forest Fire Centre (CIFFC) which is operated by provinces and other stakeholders.

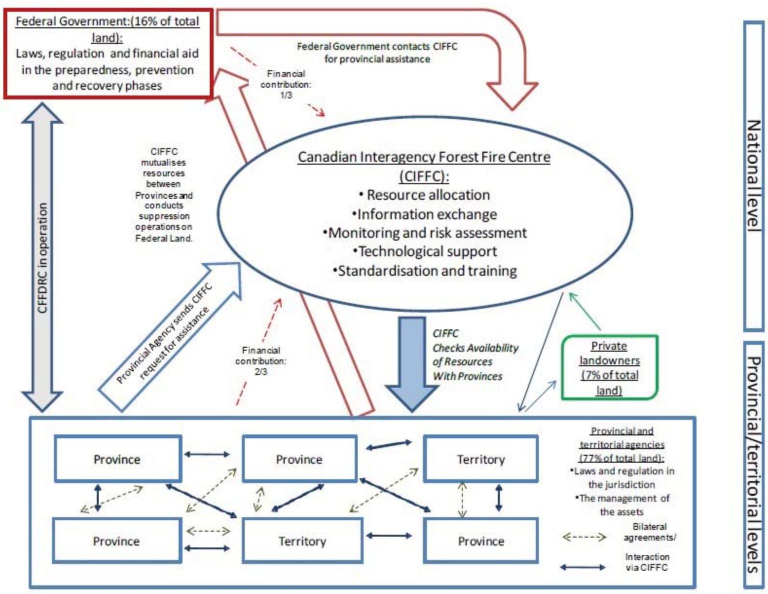


Figure 5.4: Canadian organization model.

The canadian provinces are:

- Alberta;
- British Columbia;
- Manitoba;
- New Brunswick;
- Newfoundland and Labrador;
- Northwest territories;
- Nova Scotia;
- Nunavut;
- Ontario;
- Prince Edward Island;
- Quebec;
- Saskatchewan;
- Yukon.

They are all involved in wildfire detection and suppression.

Canadian Interagency Forest Fires Centre (CIFFC) CIFFC is a Canadian non-profit organization managed by all the actors involved in wild land firefighting. The target of CIFFC is to facilitate cooperation between provinces.

The CIFFC's duties deal with:

- Resource allocation;
- Information exchange;
- Monitoring and risk assessment;
- Technological support;

- Standardization and training.

  In addition to coordinating resource sharing, mutual aid, and information sharing, CIFFC also serves as a collective focus facilitator of wildland fire cooperation. CIFFC maintains a critical strategic role in wildland fire management across Canada and internationally and provides a forum for pan-Canadian cooperation and coordination in long-range fire management planning, program delivery and human resource strategies.[18]

  Mutual Aid and Resource Sharing (MARS) is an agreement between all Canadian Provinces, which outlines three types of resources to share with each other: equipment, personnel and aircraft. This agreement is created in order to set rules in the two major problems in firefighting management, namely:

- Problems that cross jurisdictional boundaries;

- Peak-load problems created by occasional extreme demands on service capacity.[19]

  CIFFC act under MARS agreement and have two level of management.

  The Board of Corporate Trustees is made up of deputy ministers responsible for forestry representing each of the provinces and territories and the federal government. This group sets policy, given direction, and approves annual budgets for the fire centre.

  The Board of Directors is made up of the directors responsible for forest fire management in each of the provinces and territories and a representative of the federal government. This group prepares budgets and policies and controls the operation and expenditures of the fire centre. Fire centre staff operate the centre and implement programs approved by the Board of Directors and the Board of the Corporate Trustees. In addition, six working groups, made up of staff from the member agencies, have been formed to address common problems and issues, share resources, and set national standards for aviation, resource management, fire equipment, fire science and technology, national training, and forest and fire methodology. The CIFFC working groups' projects are funded on a case-by-case basis by the member agencies.[19]

In the Canadian case, aerial resources are shared amongst jurisdictions in a way that allows them to reach the wildfire quickly. In order to do this, the organization revolves around fire risk being in specific areas. These bases have spare resources in order to support adjacent areas if needed, in case the demand is above average. The system is based on the simple concept of a "quick response" in terms of detection, preparedness and attack of wildfires.

The resources of the provinces are dislocated with a risk-level logic, CFF-DRS[1] is a tool used by all the fire agencies to set alert levels. CFFDRS and its extensions indicate fire potential, however they do not offer any information about the availability of resources. Province agencies move resources to different bases following fire risk and fire weather forecasts in order to be prepared in case of fire. In order to avoid the wrong deployment of personnel or equipment, the forecast component assumes great importance to put this kind of strategy into action. With good forecasts, detection is a strong element for success in fire control activities. Detecting fire and responding to it in time means to fight against a small fire with a high level of success. This is the key point which Canadian fire management is based on.

Provincial and territorial governments have title to most forest and other wildland in Canada and thus have the primary responsibility for wildland fire response.[19]

Few provinces have a zone-approach in managing wildfires: they work on sensible-areas (managed forests or high-value areas) where facing fires is more crucial than in other zones. The remaining provinces fight each fire individually, evaluating the best strategy case-by-case. Regional responsibility declines when fires occur in National Parks or in other federal lands. In this case there is an intervention request by federal agencies through CIFFC requesting the help of provincial resources.

5.3.2 Aviation operations

Province forest service agencies manage all fixed-wing and rotary-wing aircrafts used in wildfires, both for management of forest fires and for fire suppression. All the fleets are contracted from the private sector, with long time agreements (usually from 5 to 10 years) between the parts. Pilots have to maintain an excellent level of preparation under the contract to satisfy the standards.

Several provinces use a mix of aircraft from public, private and public-private partnership fleets.[19]

The contracts show a clear season of availability of the resources, and they

[1] Canadian Forest Fire Danger Rating System

must be shared between jurisdictions in order to accomplish the MARS program. All the airplanes used for wildfires are tracked and monitored by CIFFC. This plays a crucial role in providing intelligence and balancing supply and demand in the Canadian Forest fire management framework.[15]

The Canadian wildfire management maintains a strong emphasis on the "initial attack" approach and a high level of efficiency in firefighting during the fire season. Aerial tankers usually make few sorties with a fast, heavy and rapid first strike, in order to contain the fire and allow a better action with less effort to ground crews.

A provincial/territorial agency, the federal government, or even a private landowner, can activate the CIFFC mechanism when the resources in its territorial jurisdiction are fully allocated and it needs further assistance.[15]

5.3.2.1 Aerial resource management

The dispatch arrangements provide for the immediate dispatch of an Air Tactical Group Supervisor (ATGS) in a Lead Plane aircraft and usually two firebombing aircraft loaded with retardant to such a request. This immediate response to an airtanker request from a regional fire dispatcher enables for a very rapid response and provides statistical verifiable improvements in efficiency and initial attack success.[16]

ATGS can stop any aerial attack if this is not effective. In Canada, this strategy is considered the best way to use aerial resources in wildfire management. Canadian aircraft are commonly used to support ground crews, and it is necessary for them to be rapidly available to be dispatched to new positions to operate.

The success of such an approach is directly attributable to a highly integrated reporting and fire management system that effectively provides all available information to the dispatchers and other Provincial Centres in real time. This sophisticated system supports rapid initial deployment of aerial resources and integrates all relevant information from the initial report from the public, right through to after-action reviews.[16]

A standardized system used for tracking aerial resources by CIFFC is called Automated Flight Following (AFF) system. This facilitates communications between pilots and provincial monitoring centres during interventions.[15]

AFF is a tracking system that automatically tracks the location, altitude, course and speed of an aircraft. CIFFC policy imposes that every aerial resource must have an airborne tracking tool in order to work in synergy with the

AFF monitoring system. The adoption of this standardized system has made many improvements to areas such as safety and resource awareness, and it has reduced radio-traffic control and check-in times. However, AFF is not used to replace the standard procedure or radio check-in, which takes place every thirty minutes throughout the mission. This standard is a key requirement for private contractors of firefighting fleets, both for fixed-wing and rotary-wing aircraft.

5.3.3 Financial arrangements

The CIFFC is largely funded by the provincial and territory agencies. The member agencies contribute about two thirds of the CIFFC's total revenue, with feed set according to the size of their territorial jurisdictions. The remaining one third of income comes from the federal government.[15]

Every province uses its own financial means to provide aerial assets used for fighting fires. In case the CIFFC makes use of resources belonging to a region to fight a fire in a different region, all costs will be covered by the province in difficulty. The CIFFC method is considered the most cost-effective mechanism for resource sharing.

5.4 Australia

5.4.1 Firefighting organization

In the scope of our thesis, the only southern hemisphere country we are going to consider is Australia. This country is one of the most important innovators in bushfire studies because it uses the aerial component of firefighting in a unique way. The organization is similar to the Canadian one, however there are some significant differences between these two countries as to type of environment, climate and topography. The organization of firefighting is managed at provincial level and all the regions are linked by an agency called National Aerial Firefighting Centre (NAFC).

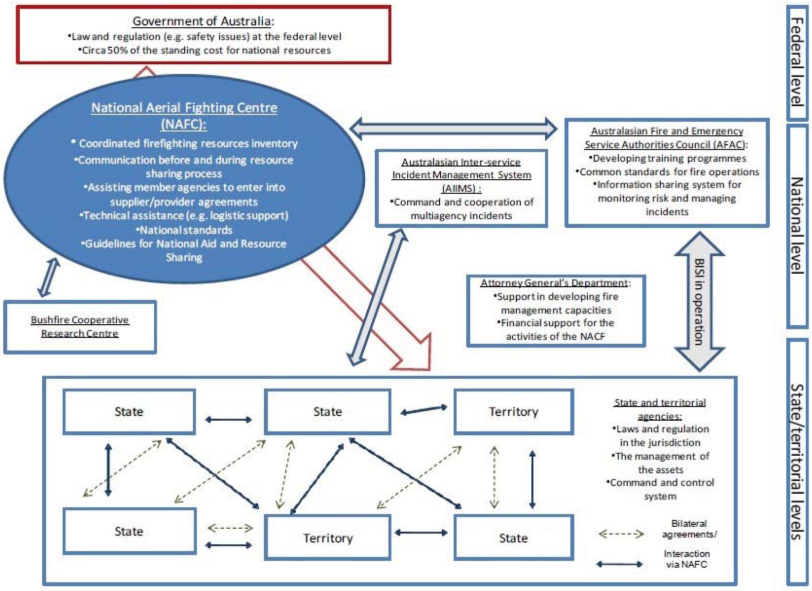


Figure 5.5: Australian organization scheme

The districts involved in bushfire action are:

- Australian Capital Territory (ACT);
- New South Wales;
- Northern Territory;
- Queensland;
- South Australia;
- Tasmania;
- Victoria;
- Western Australia.

There are four major bodies at national level which work together to face any type of emergencies. These agencies are the Attorney General's Department, the Australian Inter-service Incident Management System, the Australasian Fire and Emergency Service Authorities Council and the National Aerial Firefighting Centre. The first two government bodies help in managing wildfires; the Attorney General's Department has a supporting role in law and jurisdiction subjects from experts. In the firefighting section, the Attorney General's Department provides increasing fire management capacities and financial support for the activities of the NAFC. It provides physical assistance to requesting states or territories when they cannot reasonably cope during an emergency.[15]

The second one, the Australian Inter-service Incident Management System or AIIMS, is the nationally recognized system of incident management for the nation's fire and emergency service agencies, organizational principles and structure used to manage bushfires and other large emergencies utilizing the "all agencies" approach.

AIIMS provides a structure for delegation to ensure that all management and information functions, including incident control, operations, planning and logistics are adequately performed.[15]

It allows cooperation and command in multi-agency incidents and it derives from the ICS methodology.

Now we can better explain the other two main agencies cooperating in the bushfire management system in Australia.

Australasian Fire and Emergency Service Authorities Council AFAC is a jurisdictional body responsible for representing fire, emergency and land management agencies in Australia, New Zealand and all other territories in the Pacific area. It is composed of all the emergency-related agencies in all the areas where AFAC operates. These agencies are the main members and make up the AFAC council. Some of these agencies are affiliated members, which means they can have access to the knowledge network and AFAC support. The effective work carried out by this council is based on drawing up common standards for all types of emergency situations, in particular bushfires, and on developing training programs. Another AFAC duty is to broadcast wildfire intelligence all around the territories under governmental authority of the countries it operates in.

The main resource management report is the Bushfire Information and Significant Incidents (BISI) report. This provides information on the incident situation, resource availability and outlook across the states and territories.[15]

National Aerial Firefighting Centre NAFC is composed by seven of the eight states of the Australian territories in order to provide a cooperative national arrangement for combating bushfires.

NAFC is constituted as a limited company whose shareholders are the participating state/territories. It is governed by a Board of Directors (with nominees from each participating state/territory) and is subject to company law and regulations that also ensure transparency.[15]

NAFC has the duty to manage all firefighting aircraft at national level. It acts in order to decrease the amount of bureaucracy involved in sharing resources between states.

The model is based on resource brokering, with the NAFC playing a key coordinating role between procuring national aircraft services from commercial aircraft providers, and coordinating and assisting aerial resource sharing among state/territories.[15]

The NAFC also owns a research branch called Bushfire Cooperative Research Centre, which brings together researchers from universities, scientific and industrial organizations, private industry or public agencies in order to carry out research about cost, effectiveness and tactics to use in firefighting, with a long term collaborative partnership.

In Australia co-ordinating fire suppression (or incident control) is primarily the responsibility of the various state-based fire agencies. Exist two related aspects of bushfire incident control and they are:

- Co-ordinating the roles of different agencies during bushfire emergencies;
- Managing decision-making responsibilities between local fire fighters and centralized incident control.[20]

When the fire is not under control and it crosses territorial boundaries, the situation becomes more complex, and it becomes necessary to request the help of multiple agencies in order to co-ordinate the suppression action.

5.4.2 Aviation operations

Territories are the primary responsible for fighting fire at regional level. Every state-agency may have its own fleet made up by private contractors. In many cases they can request the use of interstate fleets through a request to NAFC, the body who draws up contracts in order to facilitate the procedures. The federal fleet handled by NAFC will be moved and based in a specific territory following a formal request by a region in need. The criteria of deployment of resources is also based on risk mitigation.

In case of deployment disputes NAFC Board makes a decision as to which state or territory the aircraft will be deployed and the period for which that state or territory will be in control of aircraft.[15]

NAFC permits to have a common standardization level in order to be all equally effective. Resource sharing between regions is a strong factor of success because it sets a clear sharing of responsibilities. Some problems used to arise in the case of inter-territorial operations, due to the lack of interoperability standards between territories.

National aircraft fleet is procured through a public tendering process. The contract, between the aircraft operator and NAFC, is designed to ensure that the aircraft can be easily moved from one state or territory onto another.[15]

5.4.2.1 Aerial resource management

All aircraft operations aimed at supporting ground crews focus on the effectiveness of an aggressive initial attack in order to be able to contain small fires and manage them easily. This tactic is used in order to give more time to ground teams to reach the fire location and to work in accordance with safety measures. The key point is to use aerial resources as soon as possible in order to attack the fire while this is still small and weak, in order to prevent its spreading. This approach is more effective with the SEAT airplane type because it can reach the fire location quickly.

NAFC has adopted a national (standard) approach to provision of tracking and event logging services for aircraft involved in firefighting and related operations. The new integrated model allows aircraft operators to select their own provider of tracking and logging services but the aircraft operator's tracking provider must arrange to forward the tracking data (to the required standard) to the assigned central integrator. The central integrator stores and forwards the data to the various user agencies and organisations.[15]

The tracking system used by NAFC is called Australian Fire Aircraft Monitoring System (AFAMS).

A key feature of AFAMS is the use of a centralized data integration service. This allows aircraft operators with compatible tracking equipment to continue to use their existing equipment, and means that operators who have yet to fit equipment have a broad choice of tracking equipment and service providers for their aircraft and operation.[21]

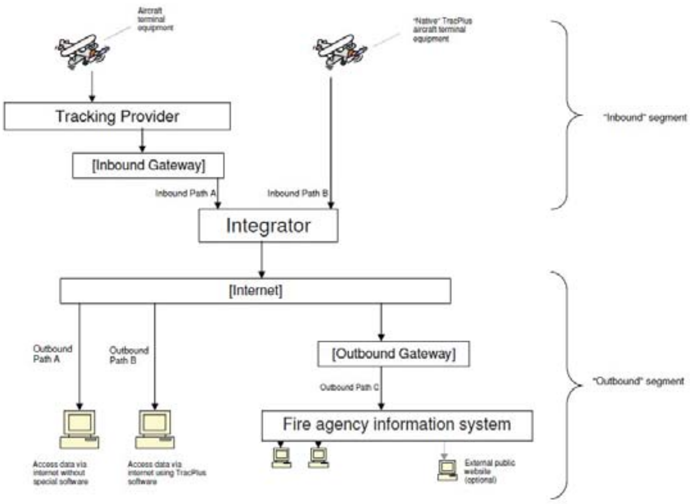


Figure 5.6: AFAMS synthetic function scheme.

5.4.3 Financial arrangements

In Australia, the federal government has greater financial involvement in the NAFC and this involvement is seen as an incentive to States and Territories to join the NAFC, however fire suppression costs are born by Provincial/territorial Authorities.[15]

Federal finance going under Attorney General's Department in the National Aerial Firefighting Arrangements, to more efficiently and effectively address the risk of bushfire across Australia. This funding will provide for a more comprehensive mix of aircraft and allow bushfire agencies and state and territory firefighting agencies to assess new aircraft and techniques on a guaranteed availability basis for the bushfire season. The national arrangements allow resources to be redeployed to areas experiencing high fire risk.[22]

5.5 France

5.5.1 Firefighting organization

France will be the only European country discussed in this analysis, the reason being its high degree of preparation to fight fires with a scientific approach and its integration of centralized structures driven by the French *Ministère de l'Intérieur*.

The fire and rescue department and national civil protection organizations have responsibility for forest fire-fighting.[23]

The emergency is faced and organized by the French *Sécurité Civile*, according to a top-down logic.

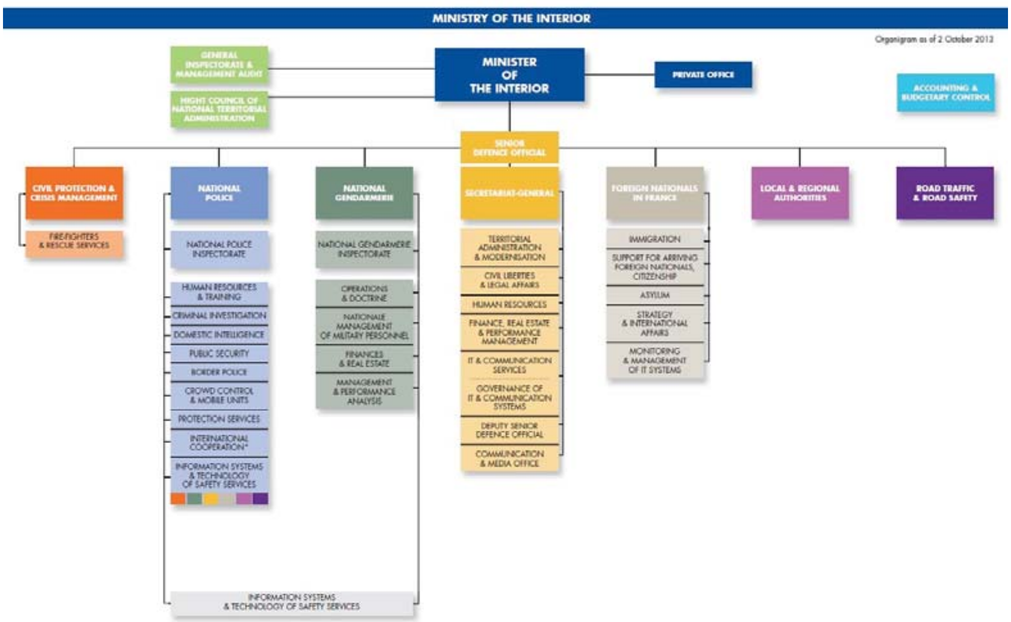


Figure 5.7: Organizational chart of the French Ministry of the Interior.

Only a few French areas are involved in fighting forest fires. These are the southern part, two south-eastern areas and Corsica. This last territory is the most dangerous part and it has similar characteristics to Sardinia (the region with one of the highest summer fire risk in Italy).

The *Ministère de l'Intérieur* is one of the most important cabinet in the French Government. The operative branch of this Ministry is *Direction de la Défense de la Sécurité Civile*, a French Government civil defense agency. It is made up of two parts: *Les Sapeur-pompiers* and *La direction générale de la sécurité civile et de la gestion des crises* (DGSCGC).

The first is composted by French firefighters acting at territorial level. The second one is the part of the agency which deals with emergency missions and aerial firefighting duties and operates at national level.

- NATIONAL LEVEL

  At national level the main body is *Centre Opérationnel de Gestion Interministérielle des Crise*s (COGIC) which has two missions: one on one hand it manages international relations with other civil protection bodies, while on the other hand it oversees civil protection in France at all levels.

  COGIC is an intermediate body between the *Ministère de l'Intérieur* and the *Centre Opérationnel de Zone*.

  It must keep the *Ministère de l'Intérieur* and the other relevant Ministers informed, monitoring and reporting processes from the lower to the upper level. At the same time, COGIC must set building-up procedures in order to manage the crisis evolution: the anticipation, the response and the national or zonal field assets deployment, according to the needs.

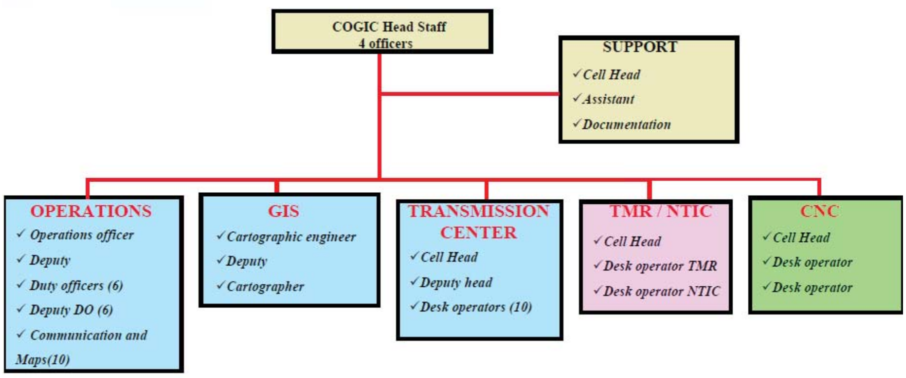


Figure 5.8: COGIC organizational chart.

- ZONAL LEVEL

  In the zonal level, the decision-making power is handled by a magistrate, while the operative structure for emergencies is called *Centre Opérationnel de Zone* (COZ). COZ is the territorial operative branch of the *Sécurité Civile*. The COZ's duties are to ensure the preparations of resources and the operative coordination in all the territories under its control, in order to face any emergencies.

  France is divided in seven defense zones encompass several administrative regions. It is the privileged area for military-civilian cooperation. It ensures that civil protection plans are coherent with military defense plans. It coordinates the activities of the local circumscription fire departments and controls the efficiency of the local means.[23]

  All the *Centres Opérationnel de Zone* are connected in order to have interaction of resources in case of needs.

Figure 5.9: COZ organizational chart.

- LOCAL LEVEL

  French regions are made up of several tiers. There are 95 "local circumscriptions" in France and each one has its own *Coordination Opérationnelle des Services d'Incendie et de Secours* (CODIS).

CODIS is the operational body for the emergency at local level.

The local headquarters directs personal, financial and operational aspects and coordinates the local fire brigades. The personnel and the engines of the brigades belongs to it.[23]

In order to keep track of how resources are being used at all times, CODIS must have an efficient information flow among all personnel. CODIS has two layers of activity: the first one occurs in normal situations, the second one in exceptional situations.

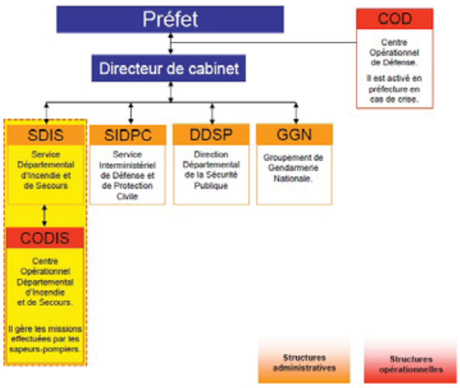


Figure 5.10: CODIS organizational chart.

There is one more tier: the Council tier. The person in charge, the town mayor, takes decisions.

France takes part in the European civil protection system. The European tier is composed of an emergency center called Emergency Response Coordination Centre (ERCC, formerly known as Monitor Information Center or MIC). It is approached when the interstate mechanism of Civil Protection is requested. It plays three important roles:

- Communications hub;
- Information provision;
- Coordination.

European countries are not the only ones to be able to request assistance, as non-EU countries are able to do so as well. International assistance is requested when a major disaster overwhelms national civil protection capacities. A multilateral sharing of resources between countries is in place in order to help one another when this is the case. France has a scientific approach to fighting wildfires, like Canada, the USA and Australia. This approach involved the creation of teaching structures, universities and research centers whose only purpose is to study emergency situations. Firefighter officers are trained in an elite structure called ECASC. The Valabre Castle Training Centre is situated in the southern part of the country and it is specialized in teaching command techniques in forest fire situations. The principles of French firefighting in forest cases are based on the anticipation of hazards. Like in Australia and Canada, a fast response against fire is the best way to have a high possibility of success in extinguishing the flames. In the French case, quick intervention is even more crucial, because topography and the type of vegetation form a unique wildland-urban interface region.

5.5.2 Aviation operations

Sécurité Civile is the body which manages all the French firefighting fleet, composed by fixed-wing aircraft.

At the provincial level Sécurité Civile supports and is supported by local fire departments. Sécurité Civile coordinates with provincial fire departments, and on behalf of them conducts initial aerial attack on fires. Sécurité Civile does not generally contract additional aircraft. Fire bombers are all purchased outright and owned by the Federal Government.[16]

Recently federal body has contracted Type 1 Helicopters to fulfill aerial requests for firefighting season. At provincial level, local fire departments hire helicopters for aerial observation, command and water bucketing.[16]

Europe sharing system In Europe exist multilateral agreement of cooperation between countries, participating in EU Civil Protection Mechanism.[15]

The core body in the operation of the European Union Civil Protection Mechanism is the Monitoring and Information Centre (MIC). MIC working as a coordination platform gives its assistance and resources to all the needed countries. It is a working body and it exchanges information in disasters worldwide. The most important role is to be a coordinator that identifies gaps and develops solutions on the basis of the information it receives, and facilitates the pooling of common resources where possible and supplies experts teams in the field of disaster to tackle problems more effectively.The MIC receives fire risk assessment information from the European Forest Fire Information System (EFFIS).[15]

5.5.2.1 Aerial resource management

The areas with the highest wildfire risk are southern France and Corsica. There are no difficulties in moving aerial resources in this country because the affected areas are geographically limited. The main base is at Marignane and all the other bases are located in southern France. All the fixed-wing aircraft of *Sécurité Civile* are based there.

Figure 5.11: Aerial bases of *Sécurité Civile.*

The importance attached to having aerial resources quickly available is such that during periods of high danger in the Provence region, aircraft are on airborne patrol and so are able to respond to any incident within this large area within just 10 minutes of notification. *Sécurité Civile* uses a model of aerial attack based on anticipation. This is possible by having aircraft fly pre-determined patrol paths during the day in the fire season. A couple of aircraft fly with a full load of retardant in order to reach the action area within a few minutes. Upon detection or notification of a fire, the patrol aircraft conduct initial attack and provide a situation report on the fire.[16] The second step of attack is taken by other aircraft, often scoopers like the CL415 or the CL215, which arrive to the location to continue the response to the fire. This approach maximizes the initial weight of attack with a strong emphasis on direct attack of small fires but does not appear to utilize a scaled response based on potential loss or eventual suppression costs.[16]

5.5.3 Financial arrangements

Sécurité Civile's funding for the procurement of aircraft is obtained through the National Minister for the Interior. Funding includes fixed-wing aircraft maintenance and procurement, pilot salaries and aviation fuel.

Provincial governements fund hire/purchase of helicopters for their fire departments directly.[16]

Chapter 6

THE ITALIAN CASE

The Italian peninsula is located in the Mediterranean basin. The northern part is dominated by the Alps, which have different meteorological conditions. Italian topography and vegetation are heterogeneous. This fact is very important because these features create both highly different vulnerable zones and different kinds of fires. The Italian climate facilitates wildfire ignition both during the summer and during the winter. The southern part of Italy has a high fire risk during the summer months (July, August and September) due to climate conditions and vegetation type. These wildfires are the most severe in the country, and are characterized by a high flame spread. They are mostly caused by long spells of high temperatures and a lack of precipitations. The Alps region is affected by winter fires, which are caused by dry winds coming from the north. These winds increase the risk of wildfire ignition in the first three months of the year. A particular case is represented by the region of Liguria, which presents a constant high risk in every fire season.

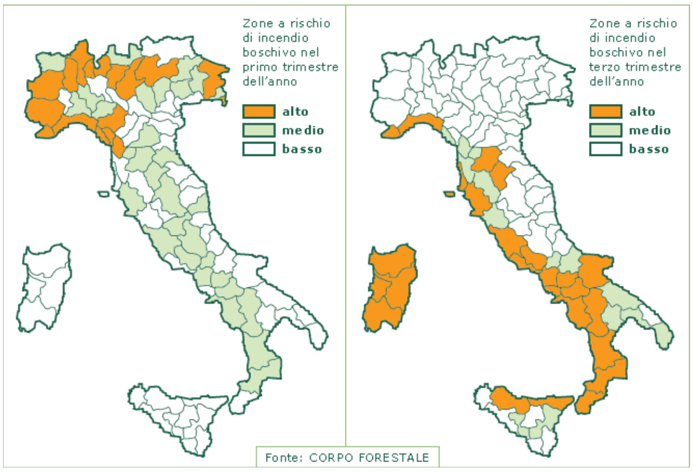


Figure 6.1: Fire risk in the first and third trimester of the year.

The Italian regions face forest fires with their own firefighting structures, which comprise several bodies.

There are:

- *Dipartimento della Protezione Civile;*
- *Corpo Forestale dello Stato;*
- *Corpo Nazionale dei Vigili del Fuoco;*
- *Forze Armate.*

6.1 The italian forest fire organization

Wildfires are handled by several bodies, however the main responsibility in case of forest fires lies with regional authorities. Every region has its own procedures, which are followed by every participating body during firefighting operations.

The alarm can be given in different ways:

- Occasional sighting: warning is given by citizens through a free number linked with CFS[1];

[1] *Corpo Forestale dello Stato*

- Ground patrol: teams of volunteers patrol the mountain paths in order to monitor the territory, they are connected by portable radio;
- Watch towers: volunteers watch the landscape in order to spot the first signs of a fire;
- Aerial surveillance: it is carried out by DPC[2] volunteers with light aircraft, operating in areas with a high fire risk;
- CCTV cameras;
- Remote sensing stations: equipped with IR/VIS cameras, they are fully automated and linked with CFS regional offices.

Warning signals arrive directly to CFS or VVF[3] and, through the respective Operative Rooms, they communicate the hazard to COR[4] or the SOUP [5].

Centro Operativo Regionale COR is the operative center managed by the *Corpo Forestale dello Stato*, and it is active 24/7 all year round. It receives intervention requests in case the main fire has been identified and sends CFS operators in order to handle the potentially dangerous situations.

Sala Operativa Unificata Permanente This center is similar to the COR, but it is slightly different. It may be located in the same office as the COR or it may be in a different place. It is activated only in case of extreme danger and during fire seasons. The SOUP personnel are from other agencies which cooperate in fire prevention (DPC, VVF and CFS). The COR and the SOUP are legislatively different bodies.

A patrol is sent to the location where a wildfire has been detected in order to verify whether the hazard is real. Ground teams, who have been trained for wildfire fighting tasks (or AIB tasks, as they are known in Italy), reach the location to extinguish the fire with conventional resources. The aerial component is sent for only if the ground teams cannot cope with their own resources. The regional fleet is the first aerial resource sent for in case of need: it is composed

[2] *Dipartimento della Protezione Civile*
[3] *Corpo Nazionale dei Vigili del Fuoco*
[4] *Centro Operativo Regionale*
[5] *Sala Operativa Unificata Permanente*

of rotary-wing aircraft contracted or owned by the regions for the fire season. If their resources are not enough, the DPC will be contacted for state fleet water bombers.

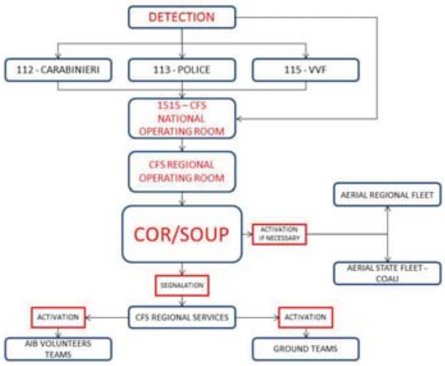


Figure 6.2: Command chain scheme for firefighting activation.

All the extinguishing operations are carried out under the orders of a CFS figure called *Direttore Operazioni Spegnimento* or DOS (nowadays DOS figures are trained for wildfire fighting purposes by civil region personnel, rather than by the CFS, like it used to happen). The DOS is a Regional Officer in charge of coordinating all the resources in the wildfire zone. He/she is responsible for ground teams and aerial resources (if they are present on the wildfire scene). He/she is also in charge of citizens' safety and as such can request exceptional measures in order to ensure the safety of the civil population. When wildfires reach human settlements, another figure is in charge of the extinguishing operations. Their title is *Responsabile Operazioni Spegnimento* or ROS, and they usually are VVF commanders. In order to request aerial resources from the state fleet, the DOS and the ROS make a request through SOUP and COR to a structure called *Centro Operativo Aereo Unificato* (COAU).

Centro Operativo Aereo Unificato This is the Operative Office of the *Dipartimento della Protezione Civile* (DPC), and it coordinates state fleet aircraft on the territory. The people who work in this office are DPC and CFS personnel, but during the fire season VVF personnel is also present. The COAU analyzes the SOUP/COR's requests and sends in aerial resources if necessary and if these are available. It is linked with all the crisis offices and all the operative sections of agencies involved in firefighting. Its duties are to:

- Manage DPS aerial resources for firefighting purposes, or to move personnel, equipment or other DPC resources;
- Coordinate aerial activity for every logistical requirement or for DPC's emergencies.

COAU manages aerial resources of other Ministries too.

After receiving state fleet aerial requests from all the active fires in Italy, a decision-making process commences involving all the COAU staff. There are many factors to consider in order to send the appropriate resources to the different fire locations. In order to make right assignment decisions, some factors are considered. These are:

- Wildfires near urban areas, services and properties;
- Actual operational situation (resources used, outstanding requests, availability forecasts);
- Aerial resources in the same zone;
- Altitude and orography;
- Type of wildfire head and vegetation around it;
- Low flight obstacles;
- Distance between wildfire and water sources, distance from home base and distance from refueling base for turnaround procedures;
- Weather and ephemeris.

These are the key points considered during the decision-making process, and in case of a high number of requests and a lack of resources, priority is given to:

- Wildfires that threat people, residential, industrial, and commercial areas, and cultural and architectural heritage;

- Wildfires within or near national and regional parks, and other areas under environmental protection;
- Wildfires neighboring urban areas or forests, with a possible risk for houses, civil and industrial structures;
- Wildfires that occur during strong wind conditions, which imply a high propagation risk;
- Wildfires in remote areas with no ground access due to natural obstacles, lack of roads or impassable forest tracks;
- Areas of reforestation;
- Coniferous forest.

In case the request can be fulfilled, the operative offices of aircraft managers are alerted and the intervention order is processed by third parties. When state fleet aerial resources are at the wildfire location, they are managed by DOS/ROS/COS, who is in charge of the extinguishing operations. In normal circumstances, the same operator will dismiss the aircraft once the wildfire is under control.

Figure 6.3: Command chain of aerial intervention over a fire.

6.1.1 Italian agencies cooperating in wildfire suppression

In Italy, there are three main agencies that play a specific role in wildfire fighting operations.

Dipartimento della Protezione Civile DPC is a national body with duties of civil protection; it is headed by the Presidency of the Council of Ministers of the Italian Republic. Its duties are forecasting, preventing, managing and overcoming human and natural disasters, emergency situations and extraordinary events at national level. The DPC is the executive branch of the Interior Ministry. National emergencies are declared by the Ministry of the Interior in accordance with regional authorities.In Italy, the Department of Civil Protection has a different organization, involving all the State organizations from the central branch to the subsidiary bodies. This architecture is designed to achieve more operative flexibility, a high scalability to match the gravity of the events and a high adaptability to different scenarios. This architecture follows a territorial structure and is characterized by decentralization. Their duties are summarized in four points explained by law N. 225/1992, and they are: forecast, prevention, rescue and restoration.

There are three levels of emergency. Level A deals with emergencies to be handled locally; Level B covers emergencies at a provincial or regional level, and Level C covers national emergencies. The latter is managed by DPC, which organizes several bodies in order to manage the critical situation.

The office involved in managing aerial firefighting situations is called *Ufficio IV – Gestione delle emergenze*, which is subordinate to the *Centro Operativo Aereo Unificato*.

COAU is the cooperative branch managing all aerial resources of the Italian minister and state fleet of water bombers.

COAU is the cooperative branch which manages all aerial resources of the Italian Ministry of the Interior and the state fleet of water bombers. It coordinates and decides how to move resources to different bases in the Italian territory following seasonal risk criteria. Personnel from different bodies work together In the COAU office, in order to manage the various emergency situations. These members of staff include CFS officers, Firefighter officers and DPC officers who come from the Italian Air Force.

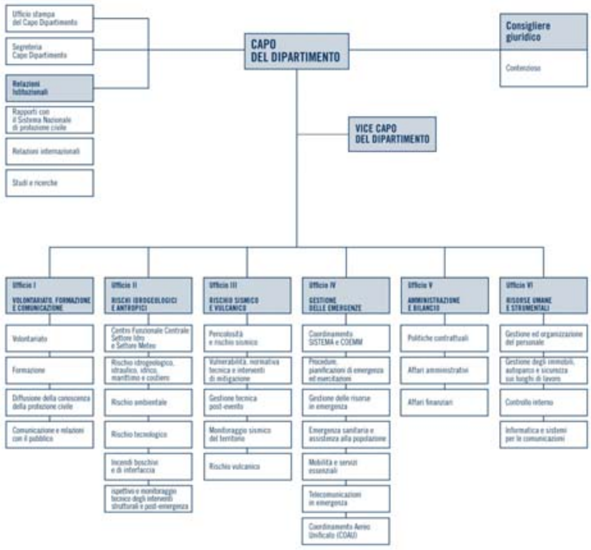


Figure 6.4: Department of civil protection organizational chart.

Corpo Forestale dello Stato The CFS is a police force which acts as criminal investigative police and carries out public security duties and other general and specific tasks.

The CFS duties include:

- Public Safety, carried out with other law enforcement duties, and concentrated in rural and mountain areas.
- Environmental and forestry policing, which involves investigating and suppressing environmental offenses and crimes against animals.
- Surveying National Parks and state protected natural areas.
- Fighting hunting crimes, with duties of control and repression of hunting offences.
- Fighting Agricultural and food offences, which involves inspecting the agricultural and food production chain in collaboration with other police bodies.
- Civil Protection and Public Assistance, the task being performed in case of natural disasters. In wildfire fighting cases, the CFS officer who has been

sent to the fire scene takes on the role of DOS and is therefore in charge of the firefighting operation. During the winter, they help other agencies in search and rescue missions.

The CFS is directly subordinate to the Ministry of Agriculture, Food and Forestry, however it has its own staff and is organized separately. It has a pyramid structure, with the General Inspectorate at the top. Below this, from top to bottom, are Regional Commands, Provincial Commands and Local Stations. There are also some intermediate offices with coordination duties. In Italy there are a few autonomous regions and provinces. These have their own Forestry police forces, which are:

- *Corpo Forestale della Regione siciliana,* for Sicily*;*
- *Corpo forestale della vigilanza ambientale* (Forestry Police for environmental monitoring, for Sardinia)*;*
- *Corpo forestale della Regione Friuli Venezia Giulia,* for the region of Friuli Venezia Giulia*;*
- *Corpo Forestale provinciale (Provincia autonoma di Bolzano),* for the province of Bolzano*;*
- *Corpo Forestale della Provincia autonoma di Trento, for* the province of Trento*;*
- *Corpo Forestale della Valle d'Aosta,* for the region of Valle d'Aosta.

Vigili del Fuoco This is the agency responsible for fire and rescue services in Italy. It is a national body and is part of the Ministry of the Interior. Its duties are: providing assistance and ensuring safety for people, animals and property, monitoring industrial activities and giving fire prevention advice. It is also in charge of ensuring public safety in case of unconventional terrorist attacks, such as chemical, bacteriological, radiological and nuclear attacks. The head of the body is represented by the *Dipartimento dei Vigili del fuoco, del soccorso pubblico e della difesa civile* (Department of Firefighting, public relief and civil defence). The executive branch is divided into three levels: Direction (regional and interregional), Provincial Headquarters and local contingents. Two regions have autonomous corps, these are Valle d'Aosta and Trentino Alto Adige. The CL-415 Canadair Italian fleet has been transferred under the command of the *Vigili del Fuoco* from the *Dipartimento della Protezione Civile*, under new financial arrangements.

6.2 The aerial component in italian firefighting

The Italian system is made up of two big actors in aerial firefighting, namely the state fleet and the regional fleets. The first one is mainly composed of fixed wing aircraft, used only when there is a specific request made by a region to the COAU center of the Department of Civil Protection. The second one is composed mostly of helicopters contracted by the regions and owned by third party companies specializing in aerial work.

Figure 6.5: Italian Regional fleets in 2013.

For our purposes, we are going to analyze the state fleet only, which is called only in case the operation of fire suppression is particularly difficult. The state fleet is mainly composed of three types of aircraft: the 19 Bombardier Canadair Cl-415, the 10 Air Tractor AT-802A Fire Boss and the 4 Sikorsky S-63F Skycrane. Each type belongs to a different organization, but they are all managed by the COAU based in Rome. The first type belongs to *Vigili del Fuoco* and is managed by a third party Spanish company called Inaer, that operates the Canadair fleet providing maintenance and Italian pilots. The Fire Boss fleet is handled like the Canadair fleet, but the company that manages it is an Italian company called SP&A. The last model is a rotary-wing aircraft owned and managed by the *Corpo Forestale dello Stato*. In emergency situations, army resources may be used in order to help the extinguishing operations, in case the demand is particularly high, especially during the fire season. COAU is the primary body that decides where to deploy all resources used in firefighting. It follows some key points in order to cover all the Italian territory, with a particular attention to inhabited areas.

The points are:

- Climate and weather forecasts;
- Statistical data;
- Regional fleet availability;
- Water Source availability;
- State fleet availability;
- Base support.

Another important point is limiting the amount of money spent in aerial firefighting, due to the current economic crisis. We are witnessing a considerable reduction in resource usage, the best example being the grounding of the AT802A and S-64F fleets, aimed at containing managing cost. The number of aircraft used during the fire season went from 33 in 2012 to 15 in 2013, a significant reduction of aerial resources. This represents a dangerous step in the firefighting system, especially in the fight against wildfires. Keeping wildfires under control is in fact paramount, as an uncontrolled fire may escape from the barriers formed by firefighters, and it may rapidly lead to a national emergency.

The high frequency of man-made fires is primarily due to a higher population density than the European average. In fact, with an area of 300,000 km^2 and a population that has long passed the 60 million mark, Italy is among the five countries with the highest population.[24]

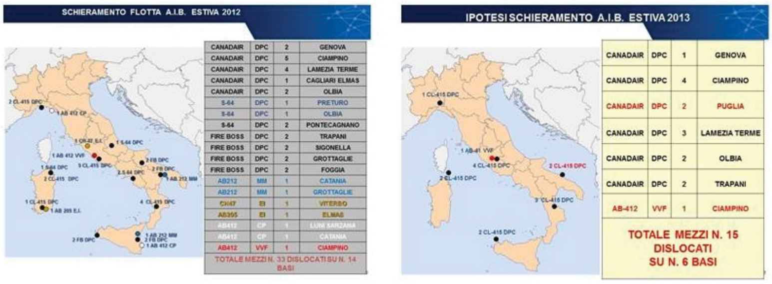


Figure 6.6: Differences between 2012 and 2013 years of resources deployements and bases used in Italy for firefighting.

Application of the aerial component in Italy In Italy, the DOS/ROS uses aerial firefighting very rarely, in order to contain the managing cost of the fleet. This is conceptually unsound, because the lack of a fast and significant aerial intervention allows for the potential spreading of wildfires. The DOS/ROS makes a request to the COAU center in an electronic format, through a computerized system called SNIPC (*Sistema Nazionale Integrato Protezione Civile*). This works by linking the airports' operative rooms to COAU and to the personnel at the wildfire location.

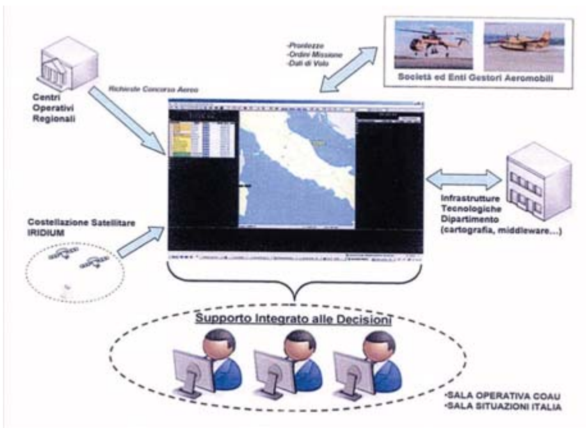


Figure 6.7: SNIPC functioning diagram.

This is an important development in order to reduce the processing time of State Fleet requests. All the resources in the wildfire area are under the control of the DOS/ROS. He/she is the only commander in charge of taking decisions and of managing both ground vehicles and rotary and fixed-wing aircraft. Analyzing the aerial component, the DOS/ROS must provide pilots with all the necessary environmental information, giving orders concerning the dropping zones and the desired action for fire suppression purposes. All the aircraft must be on the same radio frequency, in order to have all the aerial crews on the same channel. It is fundamental for flight and operational safety to maintain aerial separation. Having reached the wildfire location, the firefighter pilots will receive clearance by the DOS/ROS to drop their water payload. The DOS/ROS is the only person who can dismiss a firefighting aircraft from a firefighting operation and make it available for another mission.

Chapter 7

MISSION ANALYSIS CONCLUSIONS

During this analysis, we have found some weaknesses in the Italian aerial firefighting system, and we can divide them in three macro groups: operative problems, managing problems and information flow problems. Operative problems concern technical inadequacies of aerial firefighting, such as command chain procedures, and communication and information flow failures. We can solve these problems with engineering improvements and through an optimization of operative procedures. Managing problems mainly concern the training of personnel working in firefighting. This could be improved by adopting a more scientific approach like in other countries, such as Canada or Australia. Information flow problems are the mistakes that occur when some key information fails to be communicated to central bodies, thus making it more difficult for them to manage requests from local officers.

7.1 Managing firefighting

In the Italian system we can note some flaws in the approach to wildfire management. These can be addressed by:

- Adopting a scientific approach to wildfire fighting problems;
- Creating a joint scientific branch in order to analyze causes and find solutions for wildfires;

- Providing continuous training to mixed specialized personnel employed in wildfire fighting;
- Improving operative standards;
- Debriefing the personnel involved about wildfire operations.

All these points are linked to each other, but for a better comprehension and in order to find a solution, we will explain each point separately, and we will attempt to find a simple solution to each one of them.

7.1.1 Scientific approach

The first two points can be addressed by adopting a more scientific approach in the Italian wildfire fighting system.

The Civil Protection Department makes use of 40 national research centres for support activities on risk prevention and risk assessment. Among them, CIMA Research Foundation provide tools and methods for hydro meteorological and wildfire risk.[24]

RISICO is the operative system used to make forecasts. It works in a very similar way to FFMC[1] of FWI[2] , but with a few adjustments for the Mediterranean type of vegetation. Moreover, the only variable factor which contributes to high fire risk is represented by the dead fuel moisture for the different type of vegetation. Two of the major Italian regions affected by severe fires which adopted this method obtained positive results in terms of prediction, and in future this method will be extended to other countries in the Mediterranean basin through cooperation projects.

Forecasts provided by RISICO system are used for operational decision even in the presence of extreme events that required international assistance to deal with emergencies.[24]

According to Law 353 all the competences in connection with forest fires are transferred to the Regions[24]. This is a serious problem, which created controversy about the utilization of resources and about the lack of synergy in the operational process. Coordination groups at regional level could be counterproductive, causing internal fights between DOS and ROS over national resources.

[1]Fine Fuel Moisture Code, is a parameter used for fire danger index.

[2]Canadian Forest fire Weather Index, is an index for fire risk.

In a recent interview, the Italian ex Canadair pilot G.B. Molinaro said:

"[...]Unfortunately fires sometimes spread along the border between provinces and town territories. In these cases fights are not uncommon, as the local politicians want to secure aircraft intervention in their own territory, in order to show off [...]their own operative effectiveness. In the region of Abruzzo, I once listened to a fight between the prefects of two provinces, each one was shouting at me via radio where to drop the water. Obviously they both wanted it in their own territory [...]"[25]

One possible solution is to establish interregional bodies in order to oversee regional operations at a higher level and eventually take decisions in case of conflict, because forest fires can often turn into real civil protection emergencies, like other natural hazards.[24]

A good way to solve this problem could be to adopt a centralized control room like the NIFC in the American case, aimed at supervising and helping regions by giving resource allocation advice in relation to risk forecasts, after dividing Italy in regions by fuel type. Italy can be divided in many areas according to types of vegetation depending on the phytoclimatic zone, but we can divide it in three main flora areas:

- Mediterranean evergreen vegetation, distributed along the Italian coastline and in the main isles;
- Hardwood vegetation, mainly in the plains, hills and mountain zones;
- Coniferous vegetation, present on the Alps and on the Apennines at high altitudes: this is the most dangerous type of fuel, characterized by fire burning at high temperatures.

Another way to find a solution is to have an active collaboration between research centers and stakeholders involved in forest fires, in order to investigate and analyze data of past wildfires to reach a high level of preparation and improvement of Italian "know how" in wildfire fighting themes. A good model to follow is the Australian Bushfire CRC, a very active research center in all aspects concerning wildfire management.

7.1.2 Continous training

We will develop the last three points in this section, where we will look at all the potential improvements that can be made in order to maximize the effectiveness of firefighting operations.

In emergency missions, it is fundamental to share the same high standards of efficiency among all stakeholders.

In Italy, teams that fight against forest fires are mostly composed of volunteers. They are trained in few days and receive small rewards, which is completely unfair in relation to the manual work and the risks involved in extinguishing a fire.

It is recommended to have professional, well trained crews with a high work ethic, in order to turn fire suppression into a role requiring a high specialization. This is the direction to follow in order to optimize extinguishing procedures.

Volunteers are fundamental too, but they should only play a marginal role, and they should only be used when professional resources are occupied.

Training is an important factor in order to keep all workers at a high level of preparation as well as to maintain an excellent standard of efficiency.

A well tested model is the French one, with the School of Valabre (ECASC), where all the firefighters are trained both through courses and through simulations, with figures acting on a classical wildfire scenario. Simulations are used to maintain a high level of training even when there are no real fires to extinguish and to improve operative effectiveness among all the parties involved in wildfire suppression.

A very light device is used in the DOS operator course offered by the *Corpo Forestale dello Stato*. The course provides a simulation only of G.A.G. communications pertaining to the aerial part of firefighting, using a helicopter mockup. Another step in the standardization process in Italy is given by a new system called SI.TA.C. (*SItuazione TAttica Complessa*). This method consists of four key points aimed at analyzing the decisions made during the simulations and at making the right decisions in a real wildfire situation.

The points are:

- Analysis of the location where the wildfire has originated;
- Evaluation of wildfire development in relation to terrain characteristics;
- Identification of the right types of resources for intervention;
- Identification of the right work for every type of resources available.

This system presents a very simple model of the fire scenario, but is not enough to obtain a high level of efficiency.

Another way is to evaluate every wildfire fighting operation by debriefing all the personnel who contributed to the extinguishing mission. This is a part to not be underestimated, in order to learn from particular situations that occurred during the extinguish mission. It is also useful for a correct data collection, in order to study wildfire cases for future actions.

To maximize the initial attack support the Department of Civil Protection will:

- Produce recommendation on planning and policies to contribute to forest's health;[26]
- Provide for institutional co-operation among all stakeholders;[26]
- Develop capability to apply systematic fire management procedures;[26]
- Improve the communication command and control system;[26]
- Improve task force operations to bring professional crews on fire scene.[26]

7.2 Fire operations

We will now analyze the aerial component in firefighting, the interaction with the environment around the water bomber and what the shortcomings are concerning the management of this precious resource. Aerial operations in wildfire fighting are dangerous for several reasons, but the most important ones are linked to:

- Air traffic congestion in the fire location;
- Flying only following visual flight rules (VFR)
- Operations being only carried out when conditions for VFR flights are optimal;
- Flying at low altitudes;
- Heterogeneity of aircraft type;
- Difficulty in communications.

These are the main difficulties in a firefighting mission, and we will try to find feasible solutions for all of them.

First of all we can follow a logical order used in flight safety, which falls under the golden rules of aeronautics.

In early aviation, golden rules defined the basic principles of airmanship. With the development of technology in modern aircraft and within research on human-machine interface and crew coordination, the golden rules have been broadened to include the principles of interaction within automation and crew resource management (CRM).[27]

7.2.1 Aviate, navigate, communicate and manage – In that order

During an abnormal condition or an emergency condition, PF-PNF (pilot not flying) task-sharing should be adapted to the situation (in accordance with the aircraft operating manual [AOM] or quick reference handbook [QRH]), and tasks should be accomplished with this four step strategy:

- Aviate. The PF must fly the aircraft (pitch attitude, thrust, sideslip, heading) to stabilize the aircraft's pitch attitude, bank angle, vertical flight path and horizontal flight path. The PNF must back up PF (by monitoring and making call-outs) until the aircraft is stabilized.
- Navigate. Upon the PF's command, the PNF should select or should restore the desired mode for lateral navigation and/or vertical navigation (selected mode or FMS lateral navigation [LNAV]/vertical navigation [VNAV]), being aware of terrain and minimum safe altitude.

  Navigate can be summarized by the following:

  - Know where you are;
  - Know where you should be; and,
  - Know where the terrain and obstacles are.
- Communicate. After the aircraft is stabilized and the normal condition or emergency condition has been identified, the PF should inform air traffic control (ATC) of the situation and of his/her intentions.

  If the flight is in a condition of distress or urgency, the PF should use standard phraseology:

  - *"Pan Pan, Pan Pan, Pan Pan,"* or,

    - *"Mayday, Mayday, Mayday."*

- Manage. The next priority is management of the aircraft systems and performance of the applicable abnormal procedures or emergency procedures.[27]

These four points, used for airmanship training as a rapid aid in emergency conditions, fit well with our type of aircraft conduction for our particular mission. The first three points (aviate, navigate and communicate) are particularly important, especially as many operative problems in aerial firefighting originate almost always from the misuse of one of these three factors.

7.2.2 Wildfire environment for air traffic

When a wildfire starts, the air space above it is put under some restriction under aviation law. They are well described in AIP Italia[3], which is published by ENAV[4] every year. We can find these rules in the "En Route" section 1.3 OAT[5] traffic and point 2.b) called "forest Fire fighting flight" which explains:

"Provision DGAC 42/739/R1/6-1 dated 28/05/97.

In case of forest fires, the burning area may be overflown by military/civilian aircraft participating In fire fighting operations.

Based on airspace classification pilots not participating o firefighting operations shall comply with the following procedures:

- Airspace Class A, C and D it is prohibited to fly below 2500 ft AGL within an area of 2NM from the fire.

  REMARK If a CTR is affected by the fire, SID, STAR and approach procedures could be temporarily suspended or modified.

- Airspace Class E and G it is prohibited to fly below 3000 ft AGL within an area of 5NM from the fire. Pilots shall stay well clear of such area and shall use extreme caution flying in the vicinity of the above mentioned area in order to not interfere with possible aircraft participating in fire fighting operations.

The firefighting aircraft will have priority above all other traffic."

[3] Aeronautical Information Package.
[4] *Ente Nazionale Assistenza al Volo.*
[5] Operative air traffic.

The different sizes of these prohibited areas were connected to the level of service dispensed for VFR traffic in every airspace class. Classes A, C, and D have more restrictive control rules than classes E and G, where Class G does not count as controlled airspace. We can consider the airspace around a wildfire as a restricted zone, but there is no control in this area, therefore GAT aircraft can often violate the airspace used for firefighting operations. We must have a resource that can protect OAT traffic and provide information about all the other air traffic inside that zone.

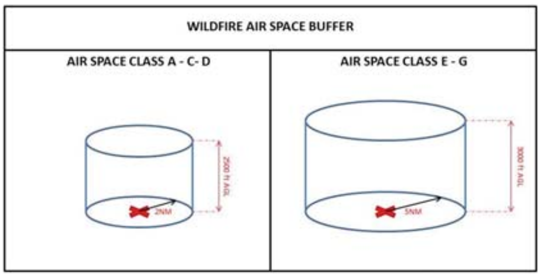


Figure 7.1: Airspace volume for firefighting operations.

All operative flights in the area are subject to VFR rules, which are simply explained in one concept:

"Pilots flying under VFR assume responsibility for their separation from all other aircraft".

So a controller resource must give traffic information to all the OAT operating in the area.

What we need is a type aircraft known as "spotter aircraft", which would be used in managing operations inside the wildfire airspace. The spotter aircraft must control all OAT traffic within the wildfire airspace and manage the information for the aerial attack, handling all the rotary and fixed-wing aircraft (they have different firefighting missions), and protecting the operation zone from possible intrusions by non-authorized traffic.

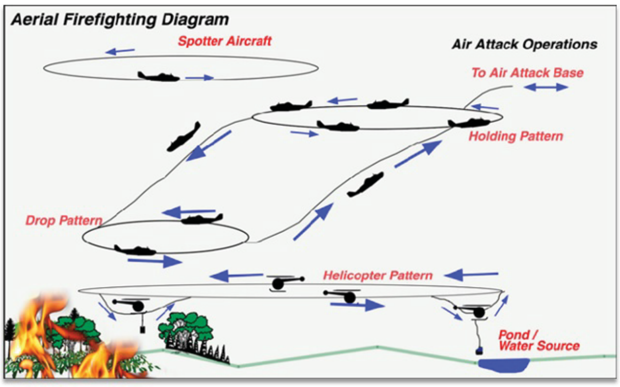


Figure 7.2: Tipical pattern for every type of aircraft involved in a firefighting mission.

7.2.3 Italian utilization of the aerial component in firefighting

In Italy, aerial firefighting is seen as a last resource: when all other methods have failed, water bombers are called in. This is a big mistake on the part of the DOS/ROS, because air support, in extinguishing terms, is extremely precious and it should be used often in cooperation with ground crews.

Combined aerial and ground suppression resources can form a suite of effective tools for agencies tasked with managing wildfires. Without ground crews and resources aircraft are limited in what they can achieve. They cannot perform all of the roles that are achievable with ground suppression resources.[28]

Aerial resources are a fundamental part of extinguishing missions, and Ground Directors should revise their approach to the utilization of this tool, in order to maximize aerial suppression effectiveness. Aerial suppression effectiveness is considered in two contexts: firstly, productivity and secondly, effect on fire behavior (i.e. rate of spread, fireline instensity). Productivity is normally regarded in terms of line construction rates. Suppression effect on fire behavior can consider fire intensity extinguished, fire progression slowed and suppression holding times. Cost efficiencies were not considered as part of aerial suppression effectiveness.[28]

Aircraft usage in wildfire suppression offers three tactical advantages that can be summed up in three key points:

- Speed, in order to reach a location in a reasonable time and faster than ground crews;

- Access, aircraft can operate in geographically inaccessible places more easily than ground crews;
- Observation, this is a fundamental point as it provides firefighters with tactical advantages and with a better awareness of the wildfire development;

Observation Aircraft are often used for detection and in observational roles during fire suppression activities as they are able to view the full extent of the fire conditions for access, fuel hazards and other potential hazards. This advantage has been used to develop the role of Air Observer (AOB) within the Incident Management System used by firefighting agencies. The AOB is responsible for obtaining and reporting accurate intelligence on fire activity and fire suppression effectiveness. Collection and relay information is not exclusive to this role. Sometimes important observations are relayed form firebombing pilots directly to ground crews. Occasionally aircraft have also been used to perform command and control services and to detect hotspots and spot fires.[28]

In Italy, access and speed are used incorrectly. The number of fires where water bombers are used is low, as Ground Directors are reluctant to use aerial resources straightaway, in order to avoid additional expenditures. However, this ends up having the opposite effect, as more flying hours will be needed in order to cool the wildfire down, if the aircraft are not promptly sent for. Consequently, this gap between number of fires and number of state fleet requests causes a higher number of flying hours and missions for the water bombers. If we begin to instil the idea that the right way to proceed is to request aerial intervention right from the start of a fire, we can reduce the cost by reducing the flying hours of the state fleet. Research has shown the effectiveness and extinguishing success of aerial intervention during initial attacks on wildfires, when the flames are small and circumscribed in a little area. A bushfire CRC's study called "The effectiveness and efficiency of aerial firefighting in Australia part 1" demonstrates how the mission success is linked with the use of aerial forces in the first attack strategy. The model takes into account the size of the wildfire according to FFDI (Forest Fire Danger Index) parameters, stating:

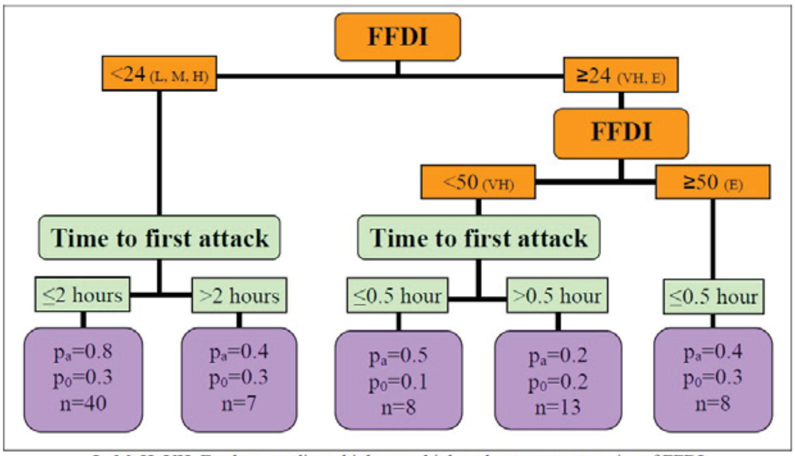
"[. . .]Area burnt on arrival was found to be the most important factor for inclusion in the model. This factor is a good measure of the suppression task on hand. Fire perimeter on arrival may have provided a better measure of the

initial suppression task. However estimation difficulties, and a probable greater margin of error, meant that initial perimeter was not used as an input variable. The Precision on estimates of area burnt on arrival was also limited in many cases.[...]"

It then talks about the other three factors used in the study:

"[...]FFDI was the second most significant factor for inclusion in the model. FFDI combines the principal fire weather variables (wind speed, temperature, relative humidity, and drought factor) into a single measure.[...] The third factor included in the logistic model was response time for aerial suppression. Aerial suppression response time was found to be more significant than the time between detection and first suppression (regardless of resource type).[...]The final factor included In the model was overall fuel hazard. This factor is based on the Overall Fuel Hazard Guide (McCarthy et al. 1999), which describes the fuel profile in terms of both hazard rating, and hazard score. This hazard rating combines the individual influences of surface, near surface, elevated (shrub) and bark fuels.[...]"

Below are some diagrams for a better explanation.



L, M, H, VH, E = low, medium, high, very high and extreme categories of FFDI
p_a= probability of first attack success with aerial suppression support
p_o= probability of first attack success without aerial suppression support
n= number of fires in each section

Figure 7.3: Decisional parameters for FFDI and first attack time.

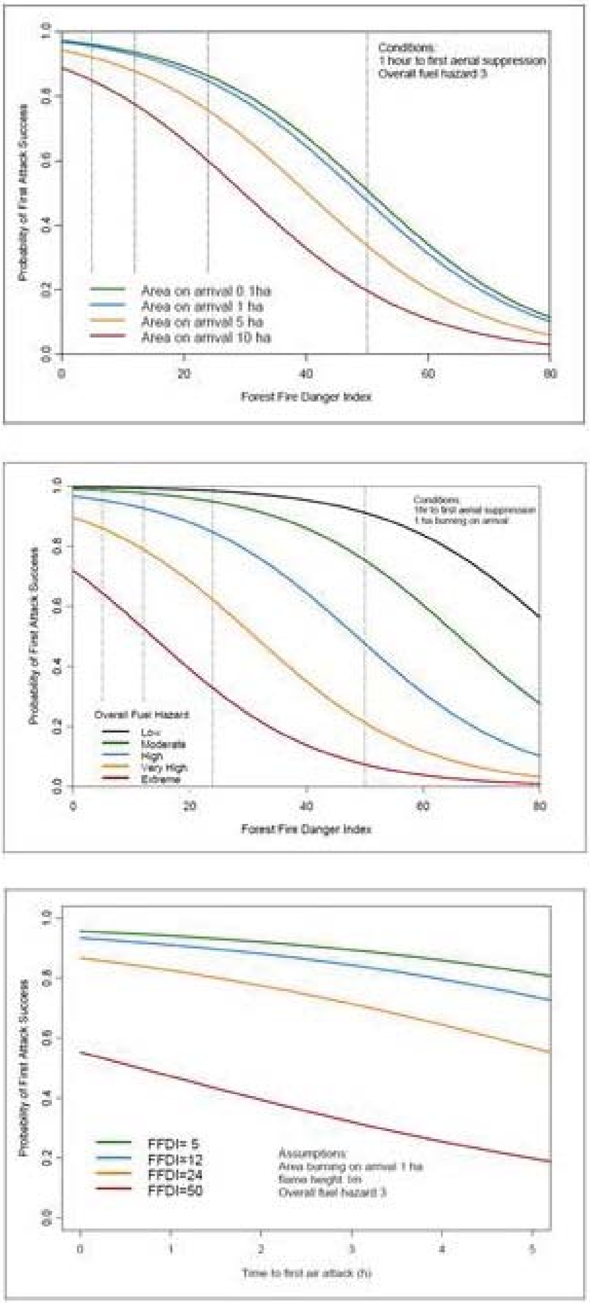


Figure 7.4: Trend lines with various parameters of probability to success in wildfire suppression.

This better explains the role of aerial firefighting in arriving to a wildfire location in time in order to begin the extinguishing operations with a small fire and with a weak flame spread. Another important factor which influences the effectiveness of an initial attack is the availability of a water source in distance terms. It is natural that a key point in a successful mission is to take water at a high rate. We can see it in two ways: the first one is to have a water source near the wildfire and the second one is to have two or more aircraft working on the same forest fire so as to have a continuous supply of water.

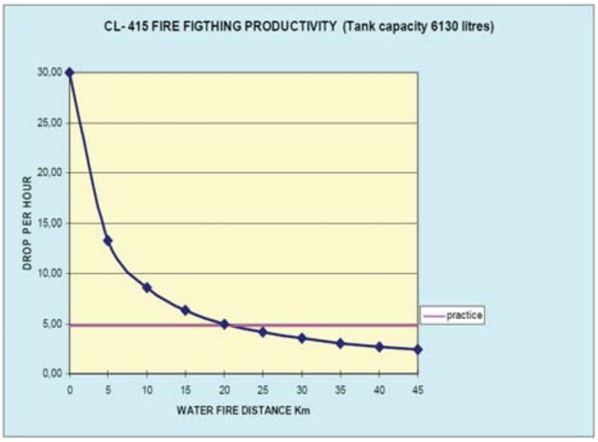


Figure 7.5: Firefighting productivity for a CL-415 in relation to the distance between scooping zone and wildifre location.

Taking into account that Canadair CL-415 is the most used water bomber in Italy (Italy has the largest CL-415 fleet in the world), it is right to compare only this performance for an initial attack carried out with fixed-wing aircraft (AT802-F is grounded due to lack of funds). The Directors of operations in Italy should understand the importance of the aerial component in firefighting, which should be used as an initial aerial attack in order to stop the flames spreading and to reduce the fire power. We can look at some data from the Department of Civil Protection, in 2012 the total number of fires in Italy was about 8700.

REGION	WILDFIRE EVENTS			TOTAL SURFACE BURNED (HA)		
	2011	2012	%	2011	2012	%
Abruzzo	136	158	16.2	1216	1772	45.7
Basilicata	295	364	23.4	3058	5717	87
Calabria	1238	1384	11.8	14436	9453	-34.5
Campania	1435	1268	-11.6	8126	6902	-15.1
Emilia Romagna	120	155	29.2	182	418	129.7
Friuli Venezia Giulia	98	181	84.7	372	801	115.3
Lazio	609	719	18.1	6877	6249	-9.1
Liguria	293	393	34.1	1517	1121	-26.1
Lombardia	227	276	21.6	1312	1247	-5
Marche	84	79	-6	449	358	-20.3
Molise	129	201	55.8	748	897	19.9
Piemonte	209	245	17.2	895	2255	152
Puglia	580	595	2.6	7172	8725	21.7
Sardegna	820	805	-1.8	10228	3314	-67.6
Sicilia	1011	864	-14.5	13385	45633	240.9
Toscana	646	623	-3.6	1026	1819	77.3
Trentino Alto Adige	43	49	14	15	49	226.7
Umbria	123	190	54.4	306	2329	661.1
Valle D'Aosta	16	12	-25	62	54	-12.9
Veneto	69	138	100	625	218	-65.1
TOTAL	**8181**	**8699**	**6.3**	**72007**	**99331**	**37.9**

Table 7.1: Number of fires and total surface burned in Italy.

For all of the fires, state fleet intervention was requested only 1766 times. This corresponds to about one request for every five fire events. The total intervention amounted to 9899 flight hours. It is our intention to reduce the flight hours, in order to reduce the usage cost of the state fleet. The best way to achieve this is linked to three concepts:

- Extensive and efficient surveillance;
- Use of aerial component for initial attack;
- Improvements in aerial coordination.

There are three golden points for a better firefighting activity in Italy.

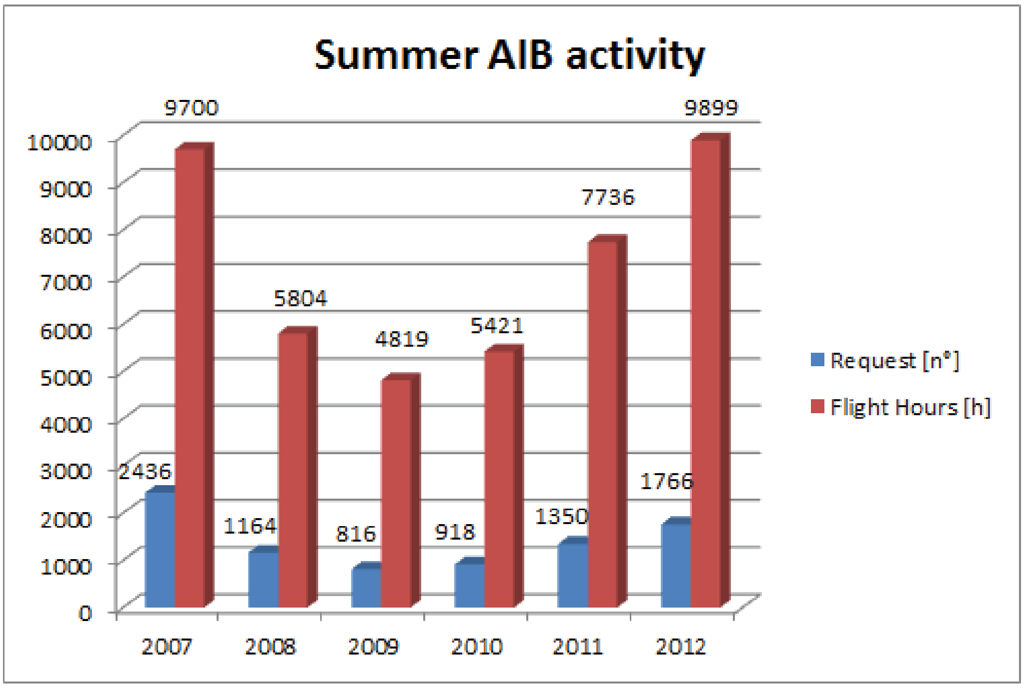


Figure 7.6: Summer Firefighting activity in Italy.

SUMMER AIB ACTIVITY 2011-2012					
YEAR	REQUESTS	MISSIONS	FLIGHT HOURS	DROPS	EXTINGUISHER
2011	1354	3633	7782	30357	170669
2012	1766	4377	9899	40029	228114

REQUESTS	MISSIONS	FLIGHT HOURS	DROPS	EXTINGUISHER
+30%	+20%	+27%	+31%	+33%

Table 7.2: Differences between 2011 and 2012 years in summer aerial forest firefighting activity.

The key points to reduce flight time costs are:

- Optimizing every single drop on wildfires

- Increasing the precision of targets;
- Evaluating the effectiveness of water bombers in each wildfire;
- Reducing dead time in mission briefings;
- Optimizing the command chain with an increased information flow between ground and air crews.

Another important point in Law N. 353/2000 is that all the responsibility of extinguishing wildfires lies with the regional authorities. As well as the state fleet, every region has its own fleet, composed only of helicopters. This is a big mistake in terms of initial attacks, as planes are a lot faster than helicopters and a wildfire mission is radically different. Helicopters are good for precision dropping, while water bombers are more useful if we have to stop fire from spreading, as they can create longer and larger retardant lines due to the higher payload they can carry. Our suggestion is to create a heterogeneous fleet composed of both rotary and fixed-wing aircraft, in order to have many solutions to approaching a fire. Bringing about this solution is particularly urgent in regions that own a big fleet, like Sardinia, whose fleet is composed of 11 helicopters. Helicopters turn out to be useless when a bushfire is accompanied by strong winds that can feed the flames: this type of extinguishing mission calls for a fixed-wing water bomber, which can move faster and can draw a bigger retardant stop line.

7.2.4 Processes optimization

In order to increase firefighting effectiveness in the Italian wildfire fighting process, we have a few suggestions to make in relation to the processes used for the suppression operations. There are two documents that explain these conclusions, namely the Italian law N. 353/2000 on forest fires and the Italian "Measures and Procedures" issued by the Presidency of the Council of Ministers, called "*Concorso della flotta aera dello stato alla lotta attiva degli incendi boschivi*" ("National aviation contribution to active wildfire fighting").

We can sum these up in three major areas:

- Aerial surveillance during high risk season;
- Aerial survey in collecting intelligence data;
- Command chain optimization.

7.2.4.1 Aerial surveillance

Like other countries operating in wildfire fighting missions, one of the most important aspects of fire control is surveillance. There are two types of surveillance: armed and unarmed. The first one is carried out with water bombers with a full payload, whose task it is to look for initial fires in order to extinguish them quickly. They fly in a predetermined pattern in high risk areas: for example, France uses a formation of two Grumman Tracker S-2, which fly over Corsica during the fire season. This is an expensive type of mission, which involves a considerable waste of extinguishing material in case no fires are spotted.

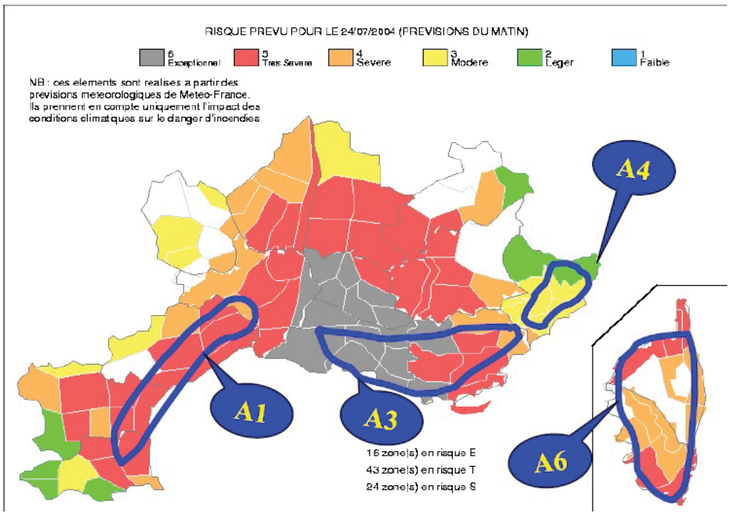


Figure 7.7: Example of active patrol patterns of french water bombers.

The second one involves pure surveillance, which is carried out by sight and with no remote sensing aid. It is often carried out by Civil Protection Volunteers with autogyros. There are also other bodies in Italy whose aim is to carry out aerial surveillance, and there are also some aerial work companies, which use ultralight aircraft in order to contain flight costs. Because of the critical state of forest fires in Italy, surveillance is still fundamental, however it is impossible to achieve a thorough and widespread monitoring of the territory. Our suggestion is to treat forest fire surveillance in a systematic way. For the high costs of active surveillance, we would opt for the second choice, but with the addition of remote sensing aid. This type of mission should be employed not only for forest fires, but also for any environment emergency that may occur in the Italian territory. ARPA[6] is concentrating its efforts in this direction, in order to have a network of intelligence and data, aimed at achieving a more scientific approach in environmental crimes and ecological monitoring.

7.2.4.2 Aerial survey

Intelligence is the next step in monitoring the environment. Italy is still connected to a satellite-based European network called EFFIS, aimed at monitoring forest fire risk. But this is not enough: we must catalog and survey all the potential fire risk areas. A good way to achieve this is to monitor the type of fuel present in high risk areas via remote sensing, in order to have more accurate predictive systems and tools to achieve a more accurate fire prevention. Moreover, we can use it to look for illegal dumping grounds or illegal construction sites, as well as other environmental crimes.

In agreement with law N. 353/2000 written in Art. N.3, subsection 3:

"The plan, which is reviewed annually, identifies:

a) The determining causes and the factors that lead to a fire;

b) The areas burned in the previous year, which are represented through cartographic means;

c) The areas subject to wildfire risk, which are represented through updated thematic maps which show the predominant vegetation in different areas;

d)The times of the year with the highest fire risk, together with wind data and wind exposure;

e) The hazard indices, determined on a quantitative and synoptic basis;

f) The actions which may determine wildfire ignition, even only potentially, in fire risk areas and times of year, mentioned under c) and d); [...]"[29]

Another key passage of the Italian law is Art. N.4, subsections 1 and 2:

"1.The activity of forecasting consists of identifying fire risk areas and times of year, as well as hazard indices, in compliance with Article 3, subsection , points c), d) and e). Forecasting also includes setting up the devices needed to carry out the active fight against fires as per Art.N.7.

[6] *Agenzia Regionale per la Protezione dell'Ambiente*, is an italian agency for environmental control and monitoring.

2. The activity of prevention consists of putting in place actions conducive to decreasing the potential ignition and causes of wildfires, as well as actions aimed at mitigating fire damage. All systems and methods to monitor and control fire risk areas mentioned under subsection 1, and the technologies for the monitoring of the territory in general are used to this end [. . .]"[29]

This passage can explain another important procedure to carry out after a wildfire, namely the aerial survey of the burned area, in order to avoid going on another mission just to collect wildfire data.

7.2.4.3 Command chain optimization

This is the crucial point of the discussion in the aerial firefighting subject. Nowadays, all resources, both aerial and ground teams, are under the command of a DOS/ROS. The DOS/ROS gives water bomber pilots clearance for a drop, and this is the main weakness of the aerial firefighting suppression procedures.

Due to lack of Communication Command and Control (C3) during the management of large fires, lots of aerial firefighting capability is lost because of:

- Lengthy procedures to request and obtain the intervention of aerial resources;[26]
- Failure of radio communication G.A.G. in fire zone, the aircraft cannot operate;[26]
- Difficult to discover in real time the objective conditions of the fire, with problems vectoring the aircraft due to the lack of standardized phraseology, clear the aircraft to operate in the zone without particularly instructions.[26]

To gain a better understanding, we will analyze the main document for Italian aerial firefighting procedures. In a suppression mission, it is essential to carry out an aerial reconnaissance of the fire area and to receive from the DOS/ROS all the necessary updates and instructions for a successful outcome. It is fundamental to have clear G.A.G. radio communications between the pilots and the DOS/ROS, but in some cases there is no radio contact between them at all.

Below are the rules to follow to operate in the absence of communications with the DOS:

- If the pilot cannot contact the DOS/ROS directly, another plane can act as a "bridge" for communications.

- In case no aircraft manages to contact the director of operations, the pilots will be able to coordinate the mission by themselves, if all the aircraft can tune in on the same channel. The pilots will need to wait for a specific authorization to proceed from COAU, which will liaise with SOUP/COR, who are in turn directly in contact with the DOS/ROS.

- If no DOS/ROS is present at the fire location, water bombers can operate autonomously after receiving the COAU authorization to proceed.

In order to avoid the occurrence of one of these three situations, we can adopt the solutions used in other countries, which will need to be adapted to Italian laws and to the type of flying environment which is produced by following OAT rules. A spotter aircraft is needed, in order to coordinate and manage all OAT traffic inside the operation area. This solution gives rise to a problem of responsibility:

"Who is the person in charge of managing the air traffic in the area?"

This question is well-founded if we analyze Law N. 353/2000 about forest fires, which states at art.7 subsection 5:

"The regional authorities will ensure the coordination of the ground operations, even in regards to the effectiveness of the aerial intervention to extinguish the wildfire. To this end, the regional authorities will be able to make use of the Corpo Forestale dello Stato (State Forestry Corps) through the Corps' operative centers."[29]

We recommend the creation of a new role, who will be under the direct command of the DOS/ROS, in order to avoid a law change. We can call this new figure *Coordinatore Operazioni Aeree* or COA ("Aerial Operation Coordinator"). In France this figure is used aboard the Beechcraft King Air to manage air traffic over big fires, but with no remote sensing aid. The same type of operations are used in other countries. For example, in Canada this figure plays a key role in firefighting operations with "bird-dog" planes. The duties of COA figures are:

- Maintaining G.A.G. radio communications between the DOS/ROS and the aerial component;

- Managing all the air traffic that is cooperating in the extinguishing operations;

- Directing, informing and organizing the aerial suppression operations;

- Protecting the operations' airspace;

- Detecting new fires, evaluating the progression of the flames;
- Evaluating the performance of the aerial component.

This figure can act as a safety barrier in any possible misunderstanding between water bomber pilots and DOS/ROS, whose personnel is constantly overloaded with information and duties. We must put the aerial component in the position of not having any lack of Communication, Command and Control, as it is the most precious tool in a wildfire mission, reducing any unsafe situation as much as possible.

7.3 Information flow

Information flow is intended for both water bomber pilots and COAU operators. Pilots need accurate information about the terrain where the fire is spreading, because the mission develops in close contact to the terrain, increasing the pilot's level of attention to all the possible obstacles on the dropping path. Often, human artifacts are not showed on the maps used in water attacks, therefore a good solution is to install a cartographic GPS aboard water bombers, in order to provide the pilots with all possible information about the area. In a context where a spotter aircraft is used, we recommend a data link system among all operating aircraft. This system should give attack coordinates so as to reduce all the radio communications to what is strictly necessary for the safety of the mission. Spotter aircraft could send updates to water bombers and to the DOS/ROS in order to evaluate new attack strategies.

From the COAU point of view, the problems in information flow are linked to making a request to the state fleet.

It is fundamental for COAU to:

- Have precise information about the location of the wildfire;
- Make prompt requests to the state fleet;
- Provide all sensible data necessary to be assigned a state resource and to be given priority.

These logistics problems can be easily overcome through a professional approach to the management of wildfire fighting operations.

Chapter 8

POSSIBLE SOLUTIONS

Following the conclusion of the mission analysis section, we have found two possible solutions: one operational and one technical solution. The operational solution revolves around the role of the Aerial Operation Coordinator or *Coordinatore Operazioni Aeree* (COA), a well-known firefighting role in other countries who has a high level of aerial firefighting know-how. The technical solution is directly linked to the COA figure, who was conceived for improving aerial firefighting effectiveness. This solution revolves around an airborne console which forms an avionics suite for firefighting operations.

If the emergency is of small size, it is not necessary to activate Air Operations positions if the function can be adequately managed at the Operations Section Chief level.[30]

8.1 *Coordinatore Operazioni Aeree* (COA)

This innovative role in the Italian aerial firefighting scenario is directly derived from Bird Dog Officers (also known as Aerial Attack Leaders or Aerial Attack Officers in other countries). The lack of this figure in the Italian system is the major flaw in the command chain operation. At the moment, the aerial part of firefighting is directed from the ground by the Incident Commander known as DOS/ROS: this creates big misunderstandings in communications and commands.

Aerial Supervision operations are conducted demanding flight conditions in a high workload/multi-tasking environment. Because of this, standardization of procedures is important to enhance/develop safety, effectiveness, efficiency, and professionalism.[31]

This figure offers an optimization of the command chain because he/she will relieve the DOS/ROS of all duties concerning aerial command, taking up all the responsibilities concerning the command of the aerial component, and cooperating actively with the incident commander on the fire scene. The DOS/ROS would maintain the control of all the extinguishing operations, would give direct orders to the COA as incident commander, and would charge him/her with directing the aerial suppression operations.

The main duties of a COA is to ensure that the aerial portion of the fire suppression operation is carried out in a safe, effective, and efficient manner.[32]

8.1.1 The right size of aerial supervision in Italy

In order to define the COA's role in the Italian firefighting scenario, we will analyze all the aerial supervision roles in suppression operations worldwide. In the American firefighting organization, there are several figures acting as aerial supervisors during a wildfire, but the scale of operations and of suppression forces is radically different in the USA scenario compared to the Italian one. In the USA, when the fire size increases, several roles come into play in the management of the extinguishing operations. These are:

- Air Tactical Group Supervisor (ATGS);
- Airtanker Coordinator (ATCO);
- Leadplane Pilot (Lead);
- Helicopter Coordinator (HLCO);
- Aerial Supervision Module (ASM).

In the USA, the command chain varies its organization depending on the type of attack they are conducting. In the case of an Initial Attack, the organization comprises few modules and is rather concise, and it can be represented by the diagram below.

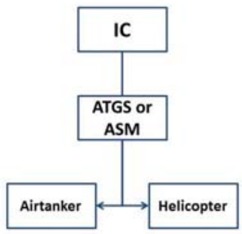


Figure 8.1: Initial attack organization in USA.

In an extended attack, the organization is more complex, and it involves several roles.

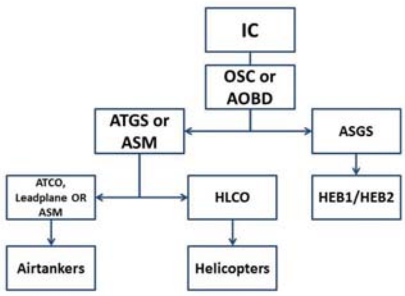


Figure 8.2: Extended attack organization in USA.

In the Italian scenario, when a fire increases in size, both aerial and ground teams are directed by an incident commander. This is very dangerous in terms of safety, because no barrier is in place to prevent misunderstandings among the parties. Integrating the COA role into the command chain could provide a safety buffer in the aerial operations.

The ATGS manages incident airspace and controls incident air traffic. The ATGS is an airborne firefighter who coordinates, assigns, and evaluates the use of aerial resources in support of incident objectives. The ATGS is the link between ground personnel and incident aircraft. The ATGS must collaborate with ground personnel to develop and implement tactical and logistical missions on an incident. The ATGS must also work with dispatch staff to coordinate the ordering, assignment, and release of incident aircraft in accordance with the needs of fire management and incident command personnel.[31]

An ASM is a two person crew functioning as the Lead and ATGS from the same aircraft. The ASM crew is qualified in their respective positions and has received additional training and authorization. An ASM can be utilized as a Lead, ATGS, or both, depending on the needs of incident management personnel. An ASM consists of an Air Tactical Pilot and Air Tactical Supervisor.[31]

Considering the requirements for the fires that can occur in Italy, the intervention model that should be adopted in Italy is the first, where the Incident Commander (DOS/ROS in Italy) gives orders to ATGS/ASM (the COA) in order to cooperate in the extinguishing operations. Another reason that backs up the adoption of the first model is the fact that it employs only one type of aircraft in fire suppression missions, namely the Canadair CL415 for the fixed-wing fleet, and Type 2 and Type 3 helicopters for the rotary-wing fleet. A coordinator for each aircraft type employed in a wildfire scenario is a useful but not a cheap solution in relation to the number of resources used.

8.1.2 COA duties

The primary responsibility of the COA was to ensure that aerial suppression operations were carried out in a safe and efficient manner.[32]

COA directs and supervises aerial attack operations on forest fires and assists in the management and administration of all aspects of the aerial fire suppression program.[32]

The best way is to give full responsibility of aerial operations to COA in order to reduce IC[1] workflow.

The COA should also cooperate with the DOS. Thanks to his aerial view of the wildfire, the COA will in fact be able to provide accurate information and operational advice to the DOS, thus enabling him to make the appropriate decisions. The COA duties in a wildfire scenario should be to:

- Receive intelligence about the incident situation;
- Brief with DOS/ROS about the incident intervention plan;
- Determine the type and the number of aircraft acting on the fire;
- Assess any increase in the use of new resources in order to improve the power of suppression;

[1]Incident Commander.

- Manage all aerial tactical activities, basing them on the intervention plan;
- Establish and maintain G.A.G. communications between the DOS/ROS and himself and between himself and the pilots;
- Coordinate the aircraft working in the incident scenario in the protected air space and to prevent air space violation by non-authorized air traffic;
- Suggest new strategies and new extinguishing tactics to the incident commander in order to increase the effectiveness of the extinguishing operations;
- Update fire intelligence about the evolving fire situation;
- Disengage the aircraft from firefighting, in case the aerial suppression activities have been ineffective.

8.1.3 Suppression organization improvements with coa figure introduction

The introduction of air surveillance aid would lead to some improvements in firefighting operations, not only in terms of command chain optimization, but also in terms of readiness and tactical advantage in situation knowledge, because the COA would be the first aerial resource to reach the incident location.

Safety is the principal consideration in all aspects of aerial supervision. A safe aviation operation depends on accurate risk assessment and informed decision making.[31]

The benefits of having a BDO[2] call the shot (as opposed to letting airtankers pilots pick their own targets) differed from agency to agency but a common belief was that an experienced BDO in charge of aerial suppression operations ensured a safer, more efficient, and more economic operation. Safer, because the BDO and BD pilot identify obstructions, terrain types, and smoke and wind conditions that are a hazard to the airtankers, and their warnings to ground crews of impending drops minimizes injury from flying debris. Coordination of air and ground attack efforts are best achieved by a BDO in consultation with the Fire Boss. A more efficient and economic suppression operations is achieved because the BDO is essentially a fire behaviour specialist who has the ability to

[2]Canadian Bird Dog Officer, is the same of COA.

assess the fire and fuel situation and to deliver the retardant/suppressant where optimum effectiveness is achieved in controlling fire spread. Effectiveness and cost optimization went hand in hand because BDO-associated where minimal compared to retardant and airtanker costs. Other reasons for having a BDOs in charge of airtanker groups were:

1. Prioritization of fire in the case of multiple starts;
2. Assessment of drop effectiveness and accuracy, and providing feedback to the tanker pilots to improve load placement and maintaining a continuous control line;
3. Provision of on-site field reports to the Fire Duty Officier;
4. Provision of on-site reports to the Fire Boss concerning fires behaviour, possible trouble spots, etc.;
5. Controlling aircraft traffic in the fire zone for safety reasons;
6. Maintaining records of flight times or airtankers and BD aircraft;
7. Recording the numbers of loads delivered by each airtanker.[32]

8.1.4 Conclusions

• The benefits achieved by introducing a COA figure can be assessed only with an in-depth study of each airtanker operation, but there are some basic advantages in having an Air Supervisor Coordinator.

- Upon arrival at the fire site, a BDO can expertly analyze the fire situation, identify ground and air suppression needs, and relay this information to Regional and/or District offices. This eliminates resource dispatching time delays which occur when reliance for information hinges on the arrival of the Fire Boss. The result is that initial attack is strengthened. The assessment may well result in no aerial action if fire growth will be inconsequential because of location, spread rate, and fuel conditions or, conversely, if fire behaviour and fuel weather parameters are such that utilization of all available resources would prove ineffective at that given time of day;

- The elimination of a time lag between the arrival of airtankers and delivery on the target while tanker crews determine where aerial deliveries should be made. The BDO will have this sorted out and will direct the airtankers accordingly on their arrival. By flying over the fire on a continuing basis, the BDO can identify changes in burning characteristics, and can react quickly in selecting target for the next airtanker drop;
- Load delivery deficiencies could be identified by the BDO and adjustments made, thereby increasing delivery efficiency;
- In the event of multiple fire starts in a given area , the BDO will be in a position to prioritize fires and work on them accordingly, thereby minimizing selection of the wrong target;
- The decision to terminate action by a BDO will be based on a knowledge of parameters affecting fire propagation. Consequently, by selective load placement, the required number of deliveries may be substantially reduced and the airtanker be available sooner for redeployment.[32]

8.2 Environment incident aerial surveillance aircraft

The second possible solution, in accordance with the introduction of COA role in a wildfire suppression scenario, is exquisitely technical. It is important to find an adequate aerial support system to achieve a successful mission outcome. All other countries involved in forest firefighting assign a central role to aerial coordination (Bird Dog Officers, Aerial Attack Leaders or Aerial Attack Officers). They use simple light aircraft or light helicopters to monitor the situation and direct all firefighting aircraft. The only sensor aid sometimes mounted on spotter aircraft is a FLIR turret, aimed at monitoring the situation in low visibility conditions, but often the only avionics device used is radio, in order to maintain G.A.G. communications.

We have found some standard requirements for spotter aircraft that we would like to see introduced in the Italian wildfire fighting system, and the golden rule to follow is the ability to be multirole. The high seasonality of wildfires in Italy (see chapter 5) calls for an aircraft that can be used in all civil protection emergency scenarios and in environmental missions.

8.2.1 Wildfire figthing mission scenario

The main duty of the spotter aircraft is to carry out firefighting missions. According to chapter 6.2 of our dissertation, the aircraft must:

- Patrol high fire risk area in the wildfire season;
- Coordinate the aerial component in over the wildfire;
- Collect wildfire data in order to study the incident and to debrief the personnel.

8.2.1.1 Patrolling

The first part of a firefighting mission for an airplane should be to patrol high risk areas during the wildfire season: this allows to intervene quickly when a wildfire occurs. The fastest way to find new fires would be to use some sensor aid, and obviously the mission must be carried out in the areas with the highest wildfire risk and must take into account the aircraft endurance. This would accelerate the activation process of the suppression chain involving the Italian agencies which contribute to firefighting operations. Moreover, it would provide the DOS/ROS with some preliminary intelligence regarding the fire location, thus enabling him/her to assess the resources needed to face the wildfire and to determine whether or not aerial intervention is necessary.

8.2.1.2 Supervision

During a wildfire, the aerial component should be controlled and supervised by the spotter aircraft. It may be the first resource to find the location or to reach the incident at a later stage (in this case the wildfire would be found in the conventional way), but in any case the spotter aircraft with the COA aboard would be the first and the fastest aerial resource to reach the fire area. This would allow to collect several parameters about the location, the wildfire and the landscape where water bombers will operate. These data will help the firefighting pilots to conduct the extinguishing mission in a safer and more efficient manner. Circling above the wildfire, the spotter aircraft crew could monitor the entire area, coordinating all the tactical aircraft involved in the suppression operations, informing the incident commander about the fire development and suggesting new extinguishing tactics if necessary. Being the COA always in contact with the DOS/ROS, the bomber pilots will be able to drop their payload at all times (in accordance with Italian wildfire fighting procedures and directives) because the order comes from the Air Supervision Module and not from ground personnel. Having a spotter aircraft monitoring the development of the fire allows firefighters to keep new spot fires or the advance of fire fronts under control, thanks to the constant support of the sensor aid. The restricted airspace would be more protected from non-authorized traffic, creating a new safety filter to prevent any involuntary dangerous situation involving GAT and OAT/BAT traffic. It could evaluate the effectiveness of the aerial component with the possibility to release the resources that could be redeployed on other targets.

8.2.1.3 Survey

In order to accomplish a scientific approach in wildfire suppression, a spotter aircraft must be able to collect intelligence and fire data during the low fire risk season or when a wildfire is being suppressed. This information is post-processed a later stage, when the aircraft have finished their mission. This would allow us to study and to keep monitoring the evolution of the fire location, to have a quick evaluation of fire damages and to debrief the involved personnel about the extinguishing mission. This could provide us with many advantages when preparing new firefighting campaigns in the Italian territory, and all the collected intelligence could be used for training purposes. Obviously the data collection is only possible with an accurate airborne sensor choice, which is expanded upon in Part II of this thesis. The ability to respond to non-seasonality requirements could provide several applications in survey missions, which are not directly linked to firefighting. The sensor suite installed onboard permits to successfully carry out patrol missions for environmental surveys and detection of environmental offenses. Being highly versatile, it can be adapted to any type of survey mission and it could also coordinate Search and Rescue missions in any type of civil protection disasters.

8.2.2 Remote sensing suite solution

We can follow one of two methods in order to enable an airplane to successfully accomplish these missions. We can either build a new aircraft or refurbish an old one. Because of the current economic crisis and because of the widespread aerial firefighting practice of adapting existing aircraft, the best method is to refurbish a good working platform. The other principle used in order to achieve a good solution is to have a remote sensing suite, which will need to be modular in order to be adapted to any aircraft used in firefighting missions. The remote sensing suite would be composed of stand-alone devices installed aboard the aircraft, and it would work independently from the normal aircraft's avionics. The Control Station receives inputs from the sensors installed on board and from the aircraft avionics suite in a unidirectional way. This allows for an easy and non-invasive integration with the main aircraft avionics. Another important point to consider is the number of crew members necessary for the mission. In other countries, spotter aircraft are used without all the sensor devices that we would install onboard, so the crew is only composed of a commander and his/her first officer, who have both been trained for firefighting duties. In our case, the best way to achieve all mission requirements is to have a crew made up of two parts, the first part composed of commander and first officers with navigation duties, and the second part composed of COA and TACO. The COA could be present in patrol and supervision missions, whereas the TACO should be present in all three parts of the firefighting mission. TACO stands for "TACtical Officer", namely the sensor operator, whose duty is to follow all the orders given by the COA in the fire suppression mission. Therefore, the crew may consist of 3 or 4 people depending on the mission. COA and TACO must sit side by side in the cabin. The Command Station will be perpendicular to the direction of flying and will be composed of two screens, in order to ensure every member of the technical crew is able to see them. The COA's seat must be provided with a bubble window in order to ensure he/she has a good view of the firefighting scenario.

8.2.3 Alternative missions

In order to achieve the non-seasonality requirements with the standard aircraft equipment, the stakeholders have assisted us in identifying more missions which a spotter aircraft equipped with an onboard command station could successfully carry out. We could divide these missions into two types, one linked to civil protection emergencies and the other one to land surveys.

8.2.3.1 Alternative land survey missions

Patrolling the territory is the best way to keep both the environment and sensible data under observation, in order to prevent natural disasters and crime proliferation. The *Corpo Forestale dello Stato* and ARPA are researching new technologies aimed at environment monitoring. Our system could be used not only to look for new wildfires and to patrol forests but also for other purposes, compatibly with the sensor suite installed onboard.

Possible survey duties could be:

- Cadastral mapping in order to record territorial changes and to monitor illegal building sites;
- Land surveys aimed at mapping fuel types in high risk areas, in order to be prepared for future intervention;
- Topographic surveys aimed at keeping thematic maps updated;
- Land surveillance for environmental offenses of any type, in particular illegal dumping grounds.

8.2.3.2 Alternative civil protection emergencies missions

Spotter aircraft could also be used for patrol and search and rescue missions, or to coordinate aerial SAR missions in case of significant natural disasters. Its airborne equipment allows to locate targets with greater precision and to coordinate rescue operations with other aerial means, if necessary, or with ground teams. It can also be used in classic maritime patrols, in order to reinforce the fleet used to monitor national waters. The alternative operations that could be carried out by this spotter plane are:

- Mountain SAR: used when the location of the incident is not known. A first flight with all the sensor equipment could be useful to narrow down the rescue area; in Italy, Alpine SAR is carried out with helicopters only and without any sensor aid, and the search is only conducted in a visual manner;
- Maritime SAR, the same as mountain case.
- Aerial coordination of rescue teams and SAR in case of significant natural disasters such as floods, earthquakes or tsunamis.

8.3 Conclusions

Unfortunately, the recent global economic crisis could have disastrous consequences also in the complex organization which has resulted in a drastic reduction of damages caused by the spread of forest fires. In fact, the resources allocated to the regions by the state are shrinking year by year. The regions, which have become autonomously organized in recent years, are now struggling to maintain the resources devoted to fire prevention and fire suppression. Furthermore, the regions are forced to completely revise the organization of the relevant structures, creating a period of great instability and uncertainty. This transition is likely to bring us back to the situation of 20 years ago. Although the organizational forest fire fighting structure was significantly improved, the vulnerability of vegetation cover was not reduced and in some cases even increased significantly.[24]

Part II

INNOVATIVE SPOTTER AIRCRAFT SYSTEM DESIGN

Chapter 9

REMOTE SENSING

9.1 Introduction

Remote sensing is defined, for our purposes, as the measurement of object properties on the earth's surface using data acquired from aircraft and satellites. It is therefore an attempt to measure *something at a distance*, rather than *in situ*. Since we are not in direct contact with the object of interest, we must rely on propagated signals of some sort, for example optical, acoustical, or microwave.[33]

For firefighting purposes, we have identified some airborne devices in order to accomplish all the mission requirements. There are four main remote sensing aids:

- Synthetic Aperture Radar;
- Flir turret;
- LiDAR;
- Aerial Photography.

An aircraft equipped with these aids is able to perform several firefighting mission types: fire search, post-fire mapping missions and command and control of aerial fire resources. Other missions could be accomplished with these sensor suites, turning this aircraft into a multipurpose platform.

9.1.1 Remote sensing, GPS and GIS integration

Remote sensing operations are possible from the ground, from air and from space. Each of these methods used to acquire information has its own characteristics in terms of size and acquisition rate. The ground method is the most accurate way to collect data, but it has a high price in terms of analysis speed and only small areas of terrain can be scanned in a time unit. On the other hand, collecting data from space is at the opposite end of the spectrum, as it enables us to scan wide areas but with a low resolution. The best choice to obtain a good balance between data resolution and size of the scanned area is to use aircraft to accomplish environmental survey missions. The use of remote sensing alone is useless without GPS and GIS systems working together. Overlooking the well-known GPS technology, we will explain in detail what a GIS system is.

GIS or Geographic Information System is a digital system for the analysis and manipulation of a wide range of geographic data with associated subsystems for other forms of input and display, used in the context of decision making.[34]

Remote sensing, GIS, and GPS are intrinsically complementary to one another in their primary functions. Each of the technologies has its limitations. If applied individually, it may be troublesome or impossible for each technology to function properly in certain applications. Only through integration can their strengths be fully utilized. Integration will not only ease their applications in resource management and environmental monitoring (e.g. wild fire fighting), but also broaden the scope to which they are applicable (e.g. real-time emergency response).[35]

The following integration models allow us to use these three features together:

- Linear model;
- Interactive model;
- Hierarchal model;
- Complex model.

The models are explained in order to give a complete picture of the integration of remote sensing, GPS and GIS.

Linear model In this model, the data flow is linear: it starts from the GPS and it finishes to the GIS box, and remote sensing is the intermediate step in the integration. This model is used in order to maximize the strength of every device. Each component does not have the same importance in the integration: the most important one is the last box, namely the GIS. The GPS is subordinated to the other two boxes, and the use of this feature is only aimed at geo-referencing data from remote sensing to the final destination of integration (GIS), bridging the gap created between the data of the last two components. The integration of geographical data between GPS can be made in three temporal modes: simultaneously, independently and post-processing. It is best practice to use the first temporal mode in airborne missions with an aircraft.

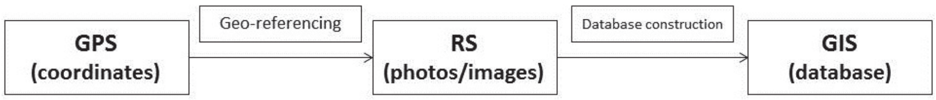


Figure 9.1: Linear model diagram

Interactive model This model differs from the linear one for the bidirectionality of the data flow. The most common flow direction remains from left to right, but it is possible to have data moving in the opposite direction. For this mode, GPS data can be mixed with remote sensing data, in order to be stored directly in GIS and used directly after integration.

Figure 9.2: Interactive Model Diagram

Hierarchical model The hierarchical model is composed of two tiers of integration. The first one is between GPS and Remote Sensing, forming the overlay tier, where images are characterized with GPS data. The last tier is called modeling: here Remote Sensing and GIS information are used, plus some mathematical models, in order to create a raster model to work with. The role of Remote Sensing in this model has become more dominant. Remote sensing supplies the primary data needed for monitoring and modeling while the GIS supplements more data, and may also provide the environment in which the modeling is undertaken. GPS still plays a subordinate albeit expanded role because GPS data are not directly involved at the second tier of integration.[35]

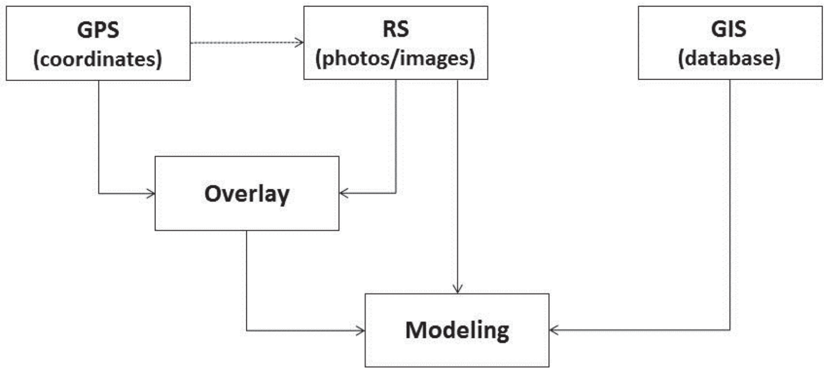


Figure 9.3: Hierarchical Model Diagram

Complex model This model represents the total integration of the three tools used in geo-referencing. Here a new connection, which was absent in the previous models, is present: this links GPS and GIS. The integration of a GIS with GPS is similar to that between remote sensing and GPS. This association is initiated when the results from GIS modeling are substantiated in the field, or when more found information at positions determined from the modeled results is collected in the field. The circular nature of integration makes it very difficult to judge the relative importance of each component. Each of the components can be of foremost importance, dependent upon the specific nature of an application.[35]

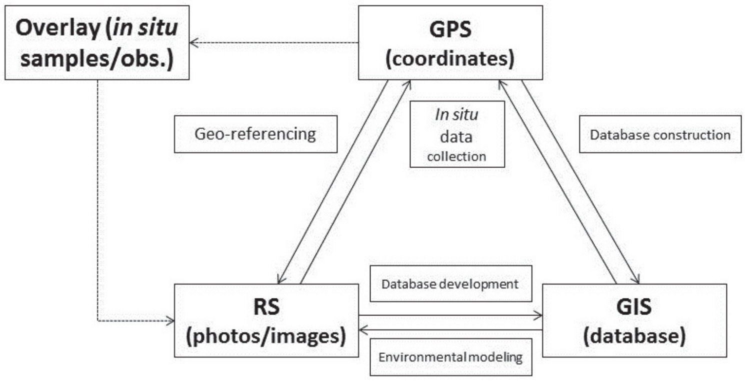


Figure 9.4: Complex Model Diagram

The use of this type of technology, which involves the integration of Remote Sensing, GPS and GIS, can be used for several applications. In our case we can distinguish four major fields of use:

- Resource Management;
- Environmental Monitoring;
- Emergency Response;
- Mapping.

9.1.2 Remote sensing and disaster management

Disaster management consists of two phases that take place before a disaster occurs, disaster prevention and disaster preparedness, and three phases that happen after the occurrence of a disaster, disaster relief, rehabilitation and reconstruction.[36]

The disaster management cycle is represented by a circle, and every phase is consequent to the previous one.

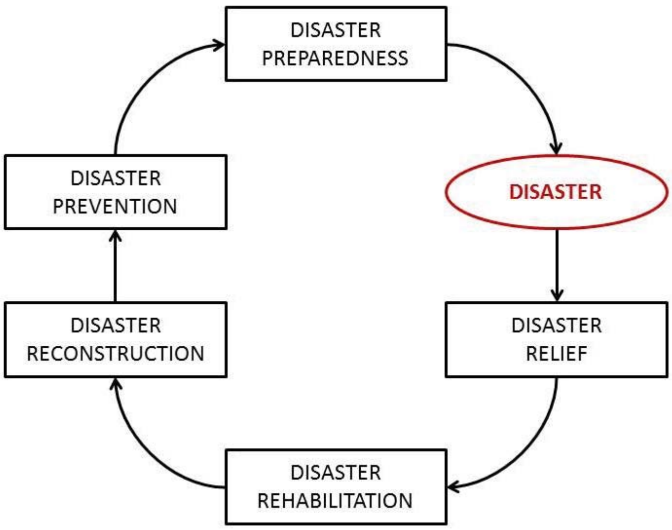


Figure 9.5: Disaster Management flow chart

Remote Sensing used for disaster management is often associated with space-based systems, and sensors installed on satellites orbiting the Earth. In some cases, space remote sensing is not adequate to provide the right information in terms of spatial resolution, timing and data type. Aerial remote sensing remains a good solution to provide intelligence with an appropriate spatial scale in relation to the disaster that has occurred.

Aerial and satellite remote sensing instruments are capable of acquiring spatially continuous datasets over large areas in otherwise inaccessible terrain. In combination with existing ground-measurement networks, such remote sensing methods can provide the important data to fill existing information gaps.[37]

Every phase of the Disaster Management Cycle has its own peculiarity, the main one is spatial resolution, which needs to be lower in prevention, reconstruction and rehabilitation and higher in preparedness and relief. All the data must to be linked to a GIS in order to have a common map-basis where all information and intelligence of a different nature must be integrated. Any disaster management project must be supported by a GIS database in order to aid operators in decision-making situations. When any type of disaster occurs, the remote sensing system must be able to collect data about the disaster swiftly, whilst monitoring the development of the situation. Remote sensing is the only tool capable of providing an adequate spatial coverage. During the relief phase, the integration of GPS, GIS and Remote Sensing is fundamental in areas literally changed due to the disaster. Remote sensing can assist in damage assessment and aftermath monitoring, providing a quantitative base for relief operations.[36]

In the rehabilitation phase, the temporal component is not the most important element, GIS is used to evaluate the damage and the rehabilitation process. Remote sensing is mostly used to update databases and maps about the actual situation. Disaster management requires data from various scientific disciplines for a correct risk assessment. These data should be correctly integrated in the decision-making process in order to have a complete database to work with. The data required for risk assessments are about:

- Catastrophic phenomena;
- Environments in which disasters might take place;
- What might be destroyed if the event takes place;
- Emergency relief resources.

The amount and type of data that has to be stored in a GIS for disaster management depends very much on the level of application or the scale of the management project. The Turn-Around-Time (TAT) is the time required between the image is obtained until the answer should be given for the warning of monitoring of a specific hazard.[36] TAT for a wildfire is very short, about 30 minutes.

The TAT depends on many factors, such as the location of the event, the satellite constellation, the weather conditions, the data receiving aspects, data analysis aspects and commercial and legal aspects.[36]Every disaster has its own sensor type to monitor the event, in particular wildfires require detailed optical images. The spatial scale of a hazard is the distinctive feature in determining the most appropriate data type to acquire. In the phase of disaster relief, satellite remote sensing can only play a role in the identification of the affected areas, if sufficiently large.[36]

There is another relationship between remote sensing type and time of data acquisition, connected with disaster management cycle phases. During the response phase, rapid acquisition of data following the event is crucial. During the recovery phase, the speed of acquisition is less important than repetition on consistent basis. In the early stages of recovery, imagery may be useful on a monthly basis, though as time passes, an annual acquisition may suffice.[38]

There are three major sensor-types:

- Optical: used in all stages of the disaster management cycle, but it expresses all its potential during the recovery phase;
- Thermal: a valuable source in the case of a wildfire, as it is not affected by phenomena that can block the view;
- SAR, a microwave sensor able to acquire data in all weather and lighting conditions.

LiDAR and GPS data are sent to the database, which uses man-made structures as reference points. Having fused the LiDAR and the database data, it is possible to determine the height of the man-made structures. In order to develop the topic of our dissertation, we must analyze some critical aspects of remote sensing tools. For our purposes, in particular for the COA role that we suggest to introduce in the Italian command chain in order to optimize aerial firefighting operations, during the response phase temporal relevance is the critical aspect of the remote sensing suite mounted on the Bird Dog plane. In the case of wildfire events, it is critical to have current and timely intelligence on the fire location, fire-front, and fuel conditions. Near-real-time information allows the fire management team to plan fire attack appropriately, consequently saving resources, time and possibly lives. Concurrently, the information must be sufficient spatial resolution to allow detailed tactical assessments and decisions to be made on the wildfire condition, and be spectrally-relevant to the phenomenon being observed and measured.[38] A key factor for a successful remote sensing mission is to have the information data ready to be used immediately by incident commanders, in order to have a "scientific" aid in the decision-making process. This is even more critical during the response phase, where decisions need to be made rapidly for a successful outcome. For a more scientific approach in firefighting, stored data of previous events could be used in the preparedness phase, in order to provide realistic scenarios based on past disasters. Another important use of stored data should be the monitoring of the effectiveness of different recovery strategies after a catastrophic event. The key elements to facilitate the usefulness of remote sensing data in support of the disaster management community are being able to provide the appropriate information in a spectrally, temporally, and spatially relevant context.[38]

9.2 Sensor description and operational use

In the previous paragraph we described the importance of integration between Remote Sensing, GIS and GPS, and what the advantages are of having an airborne or satellite platform able to collect intelligence data for disaster management. An important clarification should be made about the existing satellite which monitors forest fires in Europe, currently used by all the firefighting forces in cooperation with the EFFIS[1] program. When trying to match existing satellite capabilities to wildland fire suppression, there is a certain niche that can be filled. One problem though, is that current satellite capabilities fall short of the tactical mapping needs of the firefighting community. Currently, spatial resolution is too coarse for wildland fire intelligence purposes. Satellites that can provide daily imagery, typically provides pixels that are 1 km size and this does not provide the necessary spatial resolution.[39] The utilization of aerial or satellite sensors depends greatly on the intended application. The data quality issues of most satellite sensor imagery are widely known and several software packages exist that can assist in their analysis. In contrast, aerial systems as a level of complexity, with most images needing 'fixes' to correct for the pitch, roll and yaw of the aircraft. The advantages of aerial acquisition are that imagery with very high spatial resolutions (<0.5m per pixel) can be acquired. More importantly, aerial systems have the potential to allow a 'rapid response' system to be implemented. Given flight clearance, most aerial systems can fly on demand and thus characterize specific fire-related processes in a timely manner.[40]

[1] European Forest Fire Information System, is an european agency for fire monitoring from satellites.

Characteristic description	Type of measure	Reference examples
Flame length and height	Heat-sensitive objects	Hely *et al.* (2003)
	Direct observation	Stocks *et al.* (1996)
	Video	
Fire duration	Thermocouples	McNaughton *et al.* (1998)
		Smith *et al.* (2005*b*)
Fire temperature	Heat-sensitive paint or ceramics	Hely *et al.* (2003)
	Thermocouples	McNaughton *et al.* (1998)
	Thermal infrared cameras and imagery	Riggan *et al.* (2004)
Integrated temperature with time	Thermocouples	McNaughton *et al.* (1998)
		Smith *et al.* (2005*b*)
Rate of spread	Thermocouples	Smith *et al.* (2005*b*)
	Visual records, stop watches	Stocks *et al.* (1996)
	Video	
Direct pyrogenic emissions	Gas analyzers	Andreae *et al.* (1996)
	Fourier transform infrared spectroscopy	Yokelson *et al.* (2003)
		Yokelson *et al.* (1996)
Fuel combusted	Forest fuel and duff combustion	Ottmar and Sandberg (2003)
	In situ fire fuel sampling	Smith *et al.* (2005*a*)
	Change in laser profiling data	n/a
	Fire radiative power/energy	Kaufman *et al.* (1998)
		Wooster (2002)
Fire energy output	Fire line intensity	Byram (1959)
		Trollope *et al.* (1996)
		Smith and Wooster (2005)
	Fire radiative power/energy	Kaufman *et al.* (1998)
		Wooster *et al.* (2003, 2005)
		Roberts *et al.* (2005)

Figure 9.6: Selected examples of measures of active fire characteristics.[40]

In this section we will select remote sensing tools that are able to help operators in forest fire management, describe their functioning principles and in which missions we could use each sensor type. Our aim is to create a spotter aircraft which is able to carry out patrol, surveillance and survey missions in every stage of the disaster management cycle. Sensors in optical, thermal and radio sensor fields have been chosen in order to have the best operative superiority in wildfire detection missions and post-fire missions. We need to decide which sensors available on the market to use, in order to integrate them in an existing aircraft. These sensors are:

- FLIR turret;
- LiDAR;
- Synthetic aperture radar;
- Aerial photography.

For our purposes, the operational use of remote sensing will be analyzed in three main phases of a classical firefighting operation, which are:

- Patrol;
- Supervision;
- Survey.

9.2.1 FLIR turret

9.2.1.1 Description

Forward Looking Infrared devices, more commonly known as FLIR turrets, are the main tools used for our patrol purposes. Thanks to their thermal imagery, they are a precious aid to detect new fires. FLIR cameras are often used in surveillance missions: they are able to detect infrared radiation emitted by heat sources and to elaborate images. Airborne forward looking infrared systems use a specific type of multispectral sensor called a thermal scanner. These scanners sense only in the thermal infrared portion of the electromagnetic spectrum, detecting infrared radiation (IR) or heat emissions. Thermal scanners measure relative radiant surface temperatures rather than actual temperatures. The current temperature resolution for thermal scanners is about 0.1 degrees C. While most airborne multispectral scanners view the scene of interest directly below the sensor, FLIR systems produce oblique image views head of the aircraft. A thermal scanner system works in the following way: the system's scanner mirror receives IR radiation from the ground or object of interest. The radiation is focused on an array of thermal detectors which convert the incoming energy to an electronic signal. This signal is displayed on a monitor and recorded digitally to produce a thermal image.[41]This type of sensor is also called EO/IR, which stands for "electro-optical infrared" sensor. EO/IR systems are usually mounted on turrets and include two main sensors, a daylight CCD camera and an IR sensor. The IR sensor can target objects by their temperature difference and can operate both day and night. CCD cameras are used only in daylight and have a high magnification and resolution of objects. There are two basic ranges for infrared: long-wave and medium-wave. Long-wave infrared (LWIR) cameras usually have a few miles range for thermal imagery. Long range is more difficult because infrared radiation is absorbed by air and water vapor. Long-wave sensors may require cooling systems for the detectors to work correctly, but there are

LWIR cameras without this system. Medium-wave cameras (MWIR) are less affected by atmosphere problems than LWIR, but a cryogenic cooling system is required.

9.2.1.2 Operational use

Thermal imagery is a good aid for firefighting purposes, giving a real chance to increase the effectiveness of the firefighting process. These measurements are critical to planners and researchers attempting to map and model fire and its behavior (strategic); and for the real time assessment of fire threats and their spatial and temporal features (tactical).In the event of wildfire, suppression managers need to know where the fire is, how big it is, and how fast it is spreading. Real-time, geo-referenced parameters of actively burning fire areas are a fundamental need in the first moments of fire response.[42] We can analyze the use of the FLIR turret in the three main phases of a standard firefighting operation.

Patrol In relation to the conclusion to Part I, a good way to reduce costs in aerial firefighting is to adopt the first attack strategy. In order to implement this strategy in the Italian wildfire fighting scenario, a fundamental part is to introduce aerial wildfire patrols.To significantly mitigate the risk from and cost of wildfires, they must be detected and suppressed prior to reaching an uncontrolled state.[43] This mission achieves its maximum efficiency when it is supported by a good remote sensing tool, in our case we will analyze thermal imagery acquired by a FLIR turret. Thermal imagery helps spotter aircraft crew to locate new fires during a patrol pattern. Nowadays, the Italian procedures are based on locating a fire through satellite imagery (EFFIS) and visual recognition, both by ground patrols and warnings by members of the public.

Current wildfire suppression approaches often hinge on trying to predict where the fires are most likely to occur and "pre-staging" interdiction resources accordingly. But even when these activities are paired with important fire prevention aspects of public education, fuel load control and eliminating ignition sources during high-risk periods, the need for rapid detection and suppression is still one of the most important tools for containing wildfire damage. This typically means:

- Already having the right equipment in the right place;[43]
- Access to the most capable tools to assist suppression;[43]

- Having an accurate, up-to-date management view of a fire;[43]
- Simulation and forecasting of the fire size, speed and direction;[43]
- Making the correct resource allocation decisions.[43]

Detecting a wildfire through optical warning systems relies on the presence of smoke. However, wildfires often do not produce any smoke, making it impossible to detect them from afar. The only way to detect these wildfires is therefore by using thermal imagery. In order to reduce fire risk, it is better to carry out fire patrol patterns in areas with a high risk of forest fires, in order to reduce the search field. Other airborne forms of fire patrol are carried out in Italy by Civil Protection volunteers with autogiros, but without any kind of remote sensing, only by visual references. This could be useful in territories with a low risk of wildfire. An airborne fire patrol may reach the wildfire zone faster. This enables the crew to record intelligence about the fire size, to evaluate the type and the quantity of resources to use in the extinguishing operation, to collecting data and to give advice to the Incident Commander.

Successful fire suppression, whether conducted from the air or on the ground, is often directly proportional to the quality and timeliness of available information. The FLIR system was found to be capable of detecting small fires that are spotted outside of the main fire perimeter. This allowed suppression action to be taken at an early stage, thus restricting the growth of the main fire.[44] The initial assessment time was significantly reduced. The fire perimeter and priority areas were unquestionably and quickly delineated using the FLIR, allowing effective action to be taken as soon as the group arrived at the fire.[44]

Supervision In this phase, using a FLIR turret offers the most advantages in supporting command and control operations, in directing the water bomber and the other aerial resources and in monitoring the airspace near the wildfire. A well-known fire environment and a thorough collection of intelligence used by Incident Commanders and water bomber pilots result in a safer approach to extinguishing operations. The ability to visually monitor an operation that is habitually obscured in smoke has greatly improved the efficiency and effectiveness of air tanker utilization in a comprehensive forest fire suppression strategy.[45]

During a large fire event, the suppression tactics employed depend strongly on knowledge of a fire's current behavior. However, thick smoke columns, heterogeneous fuel structures , and dense canopy cover often conspire to make assessment of the fire situation difficult with the human eye, even from an airborne vantage point. Tasks such as differentiating the intensity of surface fuel combustion within a single fire perimeter, or locating spot fires outside of the perimeter, can become very difficult. In such cases, the enhanced view of the fire provided by airborne thermal imaging, which as mentioned above can penetrate smoke, and to some extent also vegetation cover, allows for a much better assessment of current fire behavior.[46]

Smoke is one of the problems during an aerial attack, as it drastically reduces visibility in the fire scenario. It makes water discharge operations more difficult due to a low visibility, because terrain shape is actually the major limiting factor in the extinguishing operations. The limitations deriving from the landscape influence the run orientation, direction and retardant dropping paths and the final speed and height of a drop. FLIR technology was studied in operative cases and system changes in operational tactics were recorded. Tactics used in the study are:

- Lead-In;
- Dummy Run;
- Orbit and direct;
- Called shot.

We will consider only the third one in our discussion, in relation to the spotter aircraft that we would like to introduce in the Italian wildfire fighting scenario.

Orbit and direct This technique consists in a spotter aircraft circling above a fire, with a good view of the fire area. From this position it is possible for the bird-dog to monitor theater of activity as a whole and verbally instruct the pilots as to the desired drop locations in an environment that has become quite familiar to them. Again, a FLIR system provides some distinct advantages:

- This approach provides a strategic perspective of the relevant fire behavior and development. While orbiting, the effect of the air tanker action can be evaluated and documented on the monitor and with the video recorder. Here potential problem areas can readily identified and possible solutions clearly suggested. If new or differing tactical measures become necessary due to changes in weather or fuel type, it is a simple matter to move back into the attack profile from this perspective.[45]

The FLIR system influenced firefighting strategies too. We will now consider which advantages thermal imagery brings.

Initial attack mission When this strategy is in use, the main factor of success is the control of the flames: the more intensity the fire gains, the more difficult it will be to control. If a forest fire gets into crowns of the trees and begins to roll, the increased smoke and rapid flame propagation makes accurate evaluation of retardant placement and effectiveness almost impossible.[45] Without remote sensing tools, when a wildfire went out of control, the strategy adopted was a flanking containment, with a buffer zone between the head of the fire and the retardant drop line. With the use of thermal imagery some operational improvements were made.

We can explain this in several points:

- When the retardant dropped near the flames comes in contact with them, this results in the production of smoke in the affected area, therefore FLIR becomes essential in effectively evaluating the progress of the action.[45]
- The foam or water drop is like a direct attack on the flames, so FLIR provides interesting insight into the interaction between fire and retardant. The use of infrared imaging allows an air attack officer to monitor retardant delivery precisely enough to evaluate drop effectiveness, with respect to desired outcome, with precision. This is a major advantage.[45]
- Timing plays a significant role here, and turn-around times for the air-tankers are critical. The success of most initial attack actions is dictated as much by aspects if terrain, weather, and distance as by the appropriateness of some technique. When some initial attack action is going to fail, for whatever reason, the first indicator will usually occur in the fire behavior. When blow-ups occur, the volume of smoke generated may frequently interfere with a realistic assessment of the potential for control. An experienced FLIR operator can monitor the fuel loading adjacent to the fire, identify deciduous stands, wet areas, fuel breaks, clearly see the size of the problem area, and observe the drop frequency and its effect directly. The system is capable of providing immediate indications when situations are not evolving as expected, and consequently enables efficient evaluations, coupled to a video record, of the viability of the mission as a whole.[45]

- The airspace must be well organized and controlled in any such action. One can certainly identify aircraft through the system, and it is frequently convenient to do so; yet it is essential that equipment is used to monitor the situation, not direct it. To be effective with aircraft in such a confined airspace, each pilot involved must understand the mission objective as a whole, as well as the specific role to be played by each individual part, and this necessarily involves the sharing of information. Once the attack plan has been grasped, the FLIR enables very precise monitoring and documentation of its success. The monitor provides a small, very detailed picture of a portion of a much larger situation; the information made available is certainly of value, but only with respect to a coordinated, consciously controlled airspace. This is a tool, not a technique.[45]

Support action mission This type of strategy is carried out when the fire zone is in the dormant phase, with little spot fires and a considerable amount of smoke. The spotter aircraft in orbiting mode can identify the problematic hot spots with FLIR, and it can then direct water bombers to the identified zone to drop their payload. Water bombers can in turn act as a path for the next aircraft involved in the suppression operation. The advantages of an infrared system are explained in the following points:

- Suppressant can easily be monitored from the moment it leaves the air-tanker or bucket with this system. Observing exactly how much product actually arrives as directed from a correctly triggered load is distinctly advantageous. Lower foam concentrations can be used more often with FLIR monitoring than without. The visible evidence of the drop through the FLIR, persist long after the foam vanishes to the eye, and a wetter foam tends to hang together in the air better, with more product arriving where intended.[45]

- The FLIR system facilitates locking onto the hot spots, and all the operation could be documented on video. By using the FLIR as the primary monitoring device the situational awareness of the fire extinguishing operation is increased, directing aerial resources on real targets and giving realistic information to the ground crews.

- Using the FLIR in these situations greatly reduces redundancy and uncertainty for all concerned. The FLIR allows effective minimization of the number of drops, while providing assurance of the effectiveness of the mission as whole. This is of real benefit in any cost reduction strategy, yet it also allows decisions regarding mission termination to be made with greater confidence. Both aerial and ground operations benefit from this increased efficiency.[45]

Survey In survey missions for firefighting purposes, FLIR system and thermal imagery can hardly find any application during post-fire operations. The only utilization of thermal imagery and CCD cameras is the recording of the area damaged by the wildfire. post-fire monitoring work is carried out by monitoring satellites for Earth observing missions. Other remote sensing tools discussed later in this thesis are conceived for post-fire assessment. These airborne sensors are LiDAR, aerial photography and synthetic aperture radar.

9.2.2 LiDAR

9.2.2.1 Description

LiDAR stands for "Light Detection and Ranging", and it is the main optical remote sensing technology used to carry out Earth observations. It refers to a remote sensing technology that emits intense, focused beams of light and measures the time it takes for the reflections to be detected by the sensor. This information is used to compute ranges, or distances, to objects. In this manner, LiDAR is analogous to radar (radio detecting and ranging), except that it is based on discrete pulses of laser light. The three-dimensional coordinates (e.g., x,y,z or latitude, longitude, and elevation) of the target objects are computed from 1) the time difference between the laser pulse being emitted and returned, 2) the angle at which the pulse was "fired", and 3) the absolute location of the sensor on or above the surface of the Earth.[47] There are two types of remote sensor, passive and active. Passive remote sensing is based on the principle that a phenomenon's feature is merely recorded, whereas active remote sensing records a response from a phenomenon after a signal emission. LiDAR systems are active systems because they emit pulses of light and detect the reflected light. This characteristic allows LiDAR data to be collected at night when the air is usually clearer and the sky contains less air traffic than in the daytime.[47] LiDAR uses shorter wavelengths of the electromagnetic spectrum than radar, the range of waves used may be ultraviolet, visible, or near infrared. This feature makes the sensor very sensitive to meteorological conditions, aerosols and cloud particles. In order to have a return pulse, we must have a dielectric discontinuity in the laser beam, so lasers are used to scan very small particles (like aerosols). Airplanes and helicopters are the most common and cost-effective platforms for acquiring LiDAR data over broad, continuous areas. Airborne LiDAR data are obtained by mounting a system inside an aircraft and flying over targeted areas.[47] There are two types of LiDAR: incoherent and coherent. The first is based on direct energy detection while the second type is more sensitive than the first one, and operates at a lower power, but it has the disadvantage of using a complex transceiver. Both systems can use two types of pulse: micropulse or high energy. In atmosphere research the second one is the most used. The architecture of this system is composed of four blocks: laser, optics, photodetector and receiver, and position system.

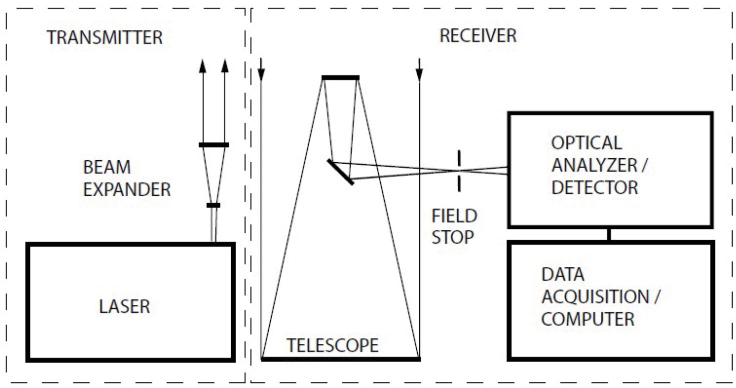


Figure 9.7: LiDAR scheme.

Laser and optics form the transmitter unit, so the receiver is composed of the electronics driving receiver and photodetector. In order to have an accurate image, the navigation and position system of the airplane are integrated into the LiDAR component, in order to achieve high precision in the data-acquiring process. The basic idea is fairly straightforward: measure the time that it takes a laser pulse to strike an object and return to the sensor (which itself has a known location due to direct georeferencing systems), determine the distance using the travel time, record the laser angle, and then, from this information, compute where the reflecting object is locate in three dimensions. In reality, to achieve a high level of accuracy, this process is a bit more complicated since it is important to know, within a centimeter or so, where the plane is as it flies at 100 or 200 miles per hour, bumping up and down, while keeping track of hundreds of thousands of LiDAR pulses per second. Fortunately, several technologies –

especially the Global Positioning System (GPS) and precision gyroscopes – came together to make it possible.[47]

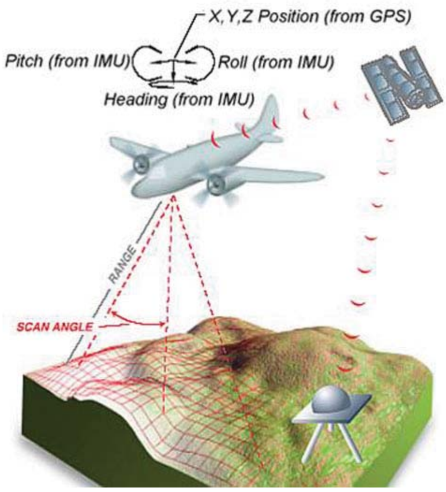


Figure 9.8: LiDAR functioning principle.

Major advancements in Inertial Measuring Units (IMU) or Inertial Navigation Systems (INS) have been instrumental in making the exact positioning of the plane possible. These systems are capable of measuring movement in all directions and parlaying these measurements into a position. They are, however, not perfect, and lose precision after a short time. A very highly sophisticated GPS unit, which records several types of signals from the GPS satellites, is used to "update or reset" INS or IMU every second or so. The GPS positions are recorded by the plane and also at a ground station with a known position. The ground station provides a "correction" factor to the GPS position recorded by the plane. Likewise, LiDAR systems have advanced considerably. Early commercial units were capable of 10,000 points per second (10 kilohertz) and were large and bulky. Newer systems are more compact, lighter, have higher angular precision, and can process multiple laser returns in the air (i.e., a second laser shot is emitted before returns from the precious laser shot are received), allowing for pulse rates of over 300,000 per second (300 kilohertz). Multiple return systems, which are common, can capture up to five return per pulse. This can increase the amount of data by 30% or more (100,000 pulses/second $\approx$ 130,000 returns/second) and increases the ability to look at the three-dimensional structure of the “features above the ground surface”, such as the forest canopy and understory.[47]

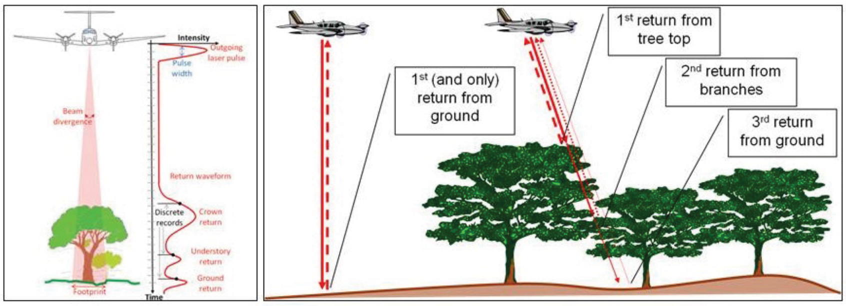


Figure 9.9: LiDAR returns examples.

9.2.2.2 Operational use

LiDAR working principles allow us to use this remote sensing tool only in the land survey phase. For firefighting purposes, this aid can help providing a more scientific approach in forest fire suppression. The only remote sensing aid to be used during an active fire by our spotter aircraft would be the FLIR turret. All the other sensors considered in our analysis are only used for post-fire assessment and landscape surveys, in order to prevent forest fire ignitions. LiDAR is a good interface in forestry and environment applications. LiDAR can collect automated measurements of vegetation, terrain, and structures from aircraft.[48] LiDAR data has proven helpful in analyzing these natural-resource tasks:

- Forest inventory;[48]
- Wildlife habitat analysis;[48]
- Predictive fire-fuels modeling;[48]
- Feature extraction;[48]
- Three-D visualization;[48]
- Watershed analysis;[48]
- Geology and engineering;[48]
- Landslide hazard assessment.[48]

In the same way we can identify some advantages in using this remote sensing type tool. The advantages have been matched to some disadvantages in order to draw a comparison.

Advantages:

- LiDAR offers detailed elevation information acquired over large areas and at a higher resolution than conventional DEMs[2];[48]
- LiDAR can reduce the costs required to collect field measurements over large areas;[48]
- LiDAR data helps pinpoint locations where field data will be useful;[48]
- The ability of LiDAR to penetrate dense vegetation allows collection of data over large surface areas that would be difficult to survey in any other way;[48]
- Morphologic features that might be missed altogether by field crews can be captured at a scale that would not be possible forma a 10-meter U.S. Geological Survey (USGS) DEM;[48]
- The interpreted data layers are easy to integrate with other data sources in a GIS;[48]
- Forest plans can efficiently incorporate results from LiDAR data analysis;[48]
- LiDAR data can be acquired during day or night under clear weather conditions.[48]

Disadvantages:

- When used for forest inventory, LiDAR data are currently still more expensive on a per-acre basis than aerial photography;[48]
- Processing and analyzing LiDAR data sets require specialized skills and software;[48]
- Although the potential for using LiDAR is still growing, not all the parameters needed to address current forestry issues, especially those related to forest inventory, can be derived from LiDAR data and the models are not always understood well enough to generalize findings from local studies;[48]

[2]Digital Elevation Models

- Where the vegetation is so dense that light cannot penetrate the ground, such ad in tropical forests, LiDAR probably won't reach the ground either, and dense undergrowth may be confused with bare ground;[48]

- Often the vegetation height calculated from LiDAR data is less than the height obtained through photogrammetry and field-work. [48]

LiDAR used in wildfire fighting is a helpful aid in the survey phase, both in pre-fire and post-fire assessment.

Survey LiDAR can be used in survey missions related to forest fire suppression in two data collection phases. The first phase is the pre-fire assessment, which consists of storing data about the vegetation, and any possible fuel and human artefacts in risk areas; the second phase consists of collecting data during post-fire assessment, evaluating damages and collecting information about the new landscape of the affected areas.

LiDAR data can be used for a variety of projects. As with aerial photography, the data-acquisition parameters influenced by the intended application.[49]

- Ground surface model: a high spatial-resolution bare-earth model representing the elevations of the surface topography;[49]

- Canopy surface model: object such as trees, buildings, and infrastructure are superimposed on the topography. In areas where the top of the vegetation data points generates the surface information, the result is a canopy surface model, which contains information about elevation of the vegetation;[49]

- Canopy height model: the crucial information required concerns the vegetation height. Which can be derived by subtracting the ground surface model from the canopy surface one;[49]

- Intensity image: beside measuring time, most sensors can also determine how much energy in the originating infrared pulse returns to the sensor. This is called intensity data, which can then be processed into a high-resolution image corresponding to a noncalibrated infrared reflection that is like an ortophoto. [49]

Unfortunately, LiDAR must only be used in the pre-fire phase in conjunction with the other two sensors installed onboard, namely SAR and Aerial Photography. LiDAR is a good remote sensing tools for post-fire operations, but it is subject to large errors.

pre-fire Utilizing a scientific approach in firefighting suppression operations means to study and be familiar with the environment where the fire is spreading. Like all wars, knowing the operations area and the fundamental characteristics of the wildfire and of its environment is of vital importance for a positive outcome. The data stored by remote sensing tools can help managers and operators to build models which are able to describe the wildfire. The use of LiDAR to accurately estimate canopy structure metrics would be a significant improvement, resulting in increased effectiveness of fuel (and fire) management programs in general. The reward of using LiDAR RS is the improvement of baseline data sources of fuel-load characteristics; these characteristics describe the distribution and density of fuel available to fire.[42] The parameters necessary to map fuels in high risk areas are several, and they are reported in the following list.

- Available canopy fuel (ACF): the foliage and fine branchwood of trees which is able to sustain crown fire;[50]
- Canopy height (CH): the highest height at which there is sufficient canopy fuel to sustain crown fire;[50]
- Canopy base height (CBH): the lowest height above the ground above at which there is sufficient canopy fuel to propagate fire vertically;[50]
- Canopy bulk density (CBD): the mass of available canopy fuel per unit volume. A measure foliage biomass divided by crown volume. [50]

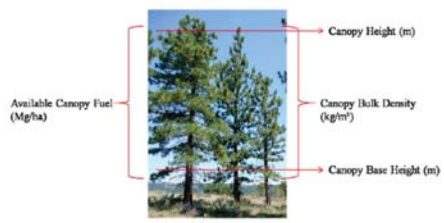


Figure 9.10: Canopy fuel metrics.

Airborne LiDAR systems also hold promise for quantifying the 3-D arrangement of canopy fuels. Specifically, the evaluation of the histograms produced from the number of LiDAR returns occurring within height strata has been shown to enable the remote determination of stand successional stage. This method may be useful for fire behavior determination§; for example, late stage successional forests have may fuel arrangements (less needle cast, fewer shrubs) that lower the propensity of crown fires. Histograms produced from LiDAR data with high pulse densities can provide information on the abundance of ladder fuels and, thereby, probabilities of crown fire initiation spread. Research to characterize vegetation structure using LiDAR and optical imagery have been used to derive metrics such as crown sizes, crown base height, tree heights, and others, on a tree-by-tree basis. Analysis of LiDAR data can also provide important stand level vegetation metrics such as stems per acre, basal area, canopy density, and canopy cover, each of which can be assessed both as pre- and post-fire variables.[51]

The main two products of LiDAR utilization for firefighting purposes are digital terrain models (DTMs) and digital elevation models (DEMs), which are the result of topography measurements. Fuel maps are derived from DEMs and DTMs.

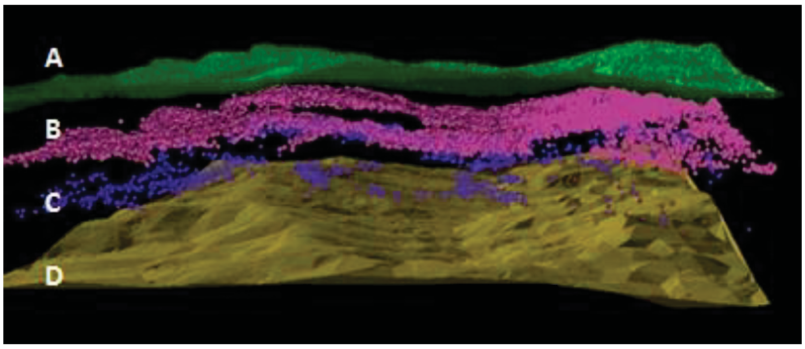


Figure 9.11: Multiple LiDAR returns from the canopy (A), the understory (B), and ground (C) displayed above a digital terrain model (D) interpolated from ground data.[50]

This is possible thanks to the ability of laser pulses to reach the ground passing through the vegetation, and to send back a series of electronically processed returns aimed at having a perfect land modeling. This allows us to cover large areas, to store a large amount of data and to cut significantly time and costs.

The image of the land surface is based on the last LiDAR return. The image is also filtered of the other returns which are related to the vegetation with an algorithm.

The main problem that can arise is that some areas might not get scanned at all due to blocking of laser pulses by topography or vegetation, especially if the scan angle is extremely shallow. Despite this, LiDAR is still far superior to high resolution near-infrared imagery in estimating canopy fuels.[52]

Fuel maps are produced from DTMs, DEMs and DSMs; the latter stands for "digital surface models", which offer a representation of all the first return from the LiDAR scan. Tree heights and vertical forest structure can be measured with a high level of accuracy using airborne LiDAR. This is significant because the vertical continuity of fuels is a major determinant in the ability for a surface fire to become an aggressive and fast-spreading crown fire.[50]

What we need is a digital canopy model (DCM) representation, simply obtained by subtracting DTM from DSM, like in the following example.

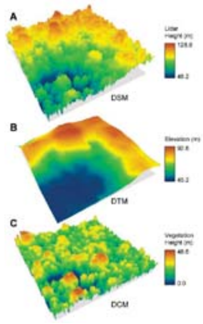


Figure 9.12: The digital surface model (A) shows the true elevation of the top of the canopy, the digital terrain model (B) shows the underlying surface elevation, and the digital canopy model (C) shows vegetation and tree heights. The digital canopy model (C) is created when the DTM (B) is subtracted from the DSM (A).[50]

Fuel maps are necessary to power decision support systems and accurate inputs produce outputs that are better able to help fire managers allocate resources based on the predicted rate and direction of spread. Improved outputs can results in better decision making and efficiencies that save thousands of dollars despite the cost of LiDAR acquisition and processing.[50] For pre-fire survey operations, we could also use aerial imagery, the only limitation being that we cannot sample simultaneously using these two remote sensing tools, because they operate best at different altitudes. Photogrammetry and LiDAR have their unique advantages and drawbacks for reconstructing surfaces. It is interesting to note that some of the shortcoming of one method can be compensated by advantages the other method offers.[53]

For a better output format, the integration between the two remote sensing tools is recommended. For a better comprehension, the following tables illustrate why the integration is so important.

	LiDAR	**AERIAL IMAGERY**
Advantages	High point density	Rich in scene information
	High vertical accuracy	High H+V accuracy
	Waveform analysis	Redundant information
Disadvantages	No scene information occluded areas	Stereo matching
	Horizontal accuracy	Occluded areas
	No inherent redundancy	Degree of automation

Table 9.1: Differences between LiDAR and Aerial Imagery.[53]

We can note that the integration of the tools used in surface reconstruction is fundamental in order to compensate for the lack of information in the other techniques. The complementary nature of the two methods is even more evident when we attempt to describe the surface explicity.[53]

Surface Properties	**LiDAR**	**Aerial Imagery**
Patches	X	
Boundaries		X
Discontinuities		X
Roughness	X	
Material Properties		

Table 9.2: Differences in surface discrimination properties between LiDAR and Aerial Imagery.[53]

Material properties could be obtained through a hyperspectral remote sensing tool. The fusion is useful for firefighting operations too, as fire managers will be able to make better decisions based on improved mapping of canopy fuels and air quality personnel can benefit for more accurate estimates of emissions.[53]

Digital true color and false color near- infrared imagery have been used extensively for forest inventory and health monitoring and the advancement of digital aerial imagery has extended the possibilities of using it in conjunction with other digital data sources such as LiDAR. LiDAR alone cannot provide all the information that canopy that is desired. Although LiDAR can accurately assess biomass and height metrics, the technology cannot discern tree species very well, unless fused with optical sensors.[53] The following flow chart illustrates the model used for fire risk assessment. The model is built with raw data from the two sensors installed, and integrated with the described vegetation parameter. By fusing LiDAR with imagery, results were obtained that maximized the strengths of each sensor.[53]

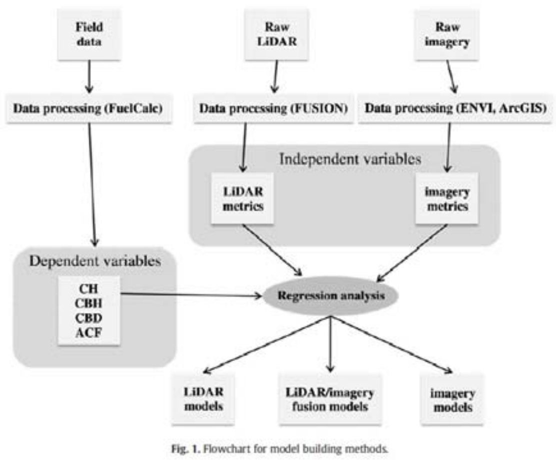


Figure 9.13: Building methods for forest characteristics with LiDAR and Aerial Imagery fusion.

post-fire LiDAR is not the best tool to use for post-fire assessment, as this method of collecting data is subject to large errors and wildfire managers prefer to use tools that are be able to distinguish reflectance characteristics of burned areas. Remotely sensed data have been extensively used for burnt area mapping. Fires produce a significant change in the structure and the reflectance of vegetation and the soil properties within the burnt area that are noticeable in the microwave visible and especially the infrared part of electromagnetic spectrum.[54] As regards the post-fire aspect, the role of aerial photography and synthetic aperture radar will be investigated in the following chapters.

9.2.3 Aerial photography

9.2.3.1 Description

Aerial photography refers to the platform where the sensor is mounted and to the type of sensor used to collect data. The sensor is a camera and the science branch is called photogrammetry. This is defined as: [...] is the science of obtaining reliable information about properties of surfaces and objects without physical contact with the objects, and of measuring and interpreting this information.[55]

Photogrammetry uses passive sensors as cameras, which capture radiant energy reflected from objects in order to produce images. The photogrammetric process is divided in three stages, the first one is data acquisition, where the sensor collects the information. Photogrammetric procedures are the link between the final product of post-processing and the acquisition of information. Photogrammetric products are all the final objects that aerial photography and post-processing techniques are able to produce.

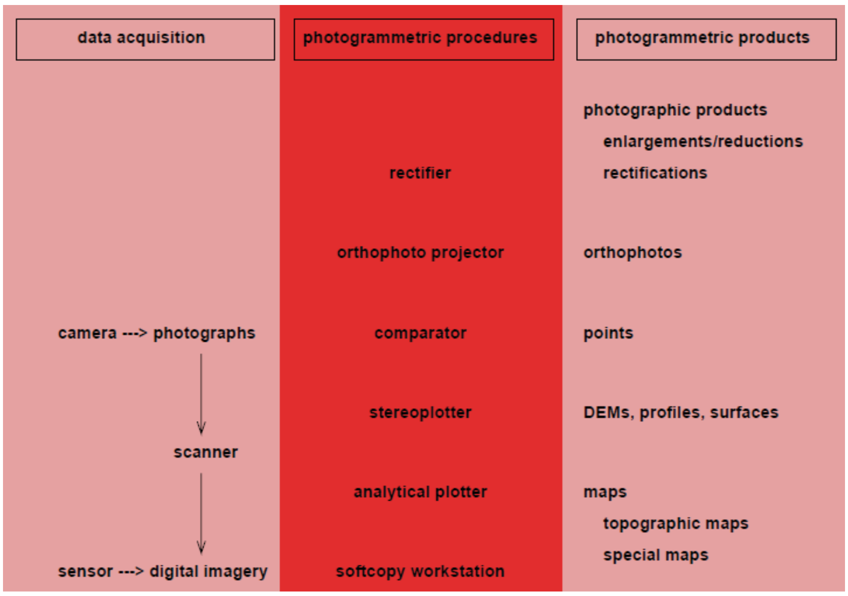


Figure 9.14: Products of aerial phorography.

Photogrammetry is based on acquiring information and interpretating them. The remotely received information can be grouped into four categories:

- Geometric information: involves the spatial position and the shape of objects. It is the most important information source in photogrammetry;[55]
- Physical information: refers to properties of electromagnetic radiation, e.g., radiant energy, wavelength, and polarization;[55]
- Semantic information: is related to the meaning of an image. It is usually obtained by interpreting the recorded data;[55]
- Temporal information is related to the change of an object in time, usually obtained by comparing several images which were recorded at different times.[55]

In order to have an exact image interpretation derived from remote sensing, some elements must be taken into account. The more elements are used, the higher the degree of complexity of image interpretation will be. The elements are subdivided in four major groups:

- Primary: refers to the basic elements of interpretation such as tones and colors of the images;
- Secondary: refers to the elements relative to the absolute and relative size of the objects in the images, and to the shape and texture of the photograph (image definition and scale);
- Tertiary: refers to the pattern of the objects in the photograph, which is linked to their spatial arrangement, height and shadows (the latter is a problem in features recognition);
- Quaternary: refers to the topographic recognition of the site and to the objects' features in the images.

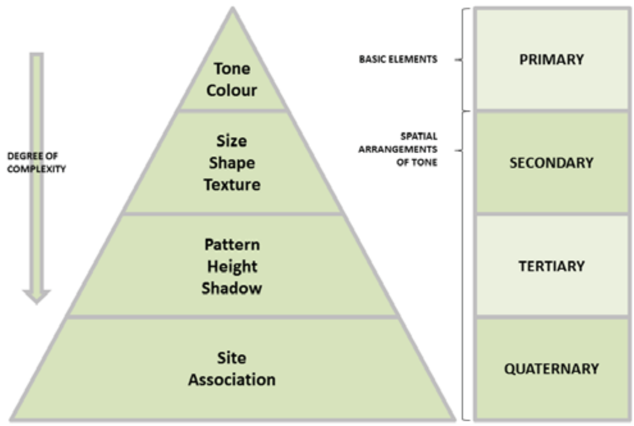


Figure 9.15: Elements of aerial photography.

Aerial photography is the basic data source for making maps by photographic means.[55] There are many factors and many techniques that influence the results of a photography mission. The quality of aerial photography is influenced by:

- Design and quality of lens system;
- Quality of the camera;
- Photographic material;
- Development process;
- Weather conditions and sun angle during the flight.

Aerial photograph classification is linked to some properties of the techniques used in data collection, these are the orientation of the camera axis, the focal length of the camera and the type of emulsion. There are three possible camera orientations, which are related to the angle at which the image is taken. These are:

- True Vertical;

- Near Vertical;
- Oblique photograph that splits into high and low oblique.

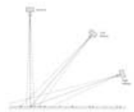


Figure 9.16: Camera orientation types.

The emulsion type depends on the missions' target and the sensitivity varies inversely in relation to the emulsions' grain size. Panchromatic black and white is the most widely used type of emulsion for photogrammetric mapping. Color photography is mainly used for interpretation purposes. Recently, color is increasingly being used for mapping applications. Infrared black and white is used in adverse weather conditions and false color is mainly used to analyze vegetation.

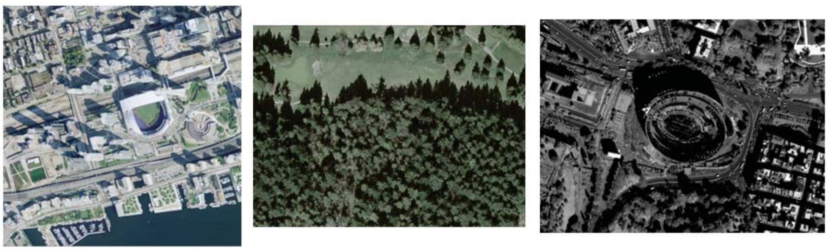


Figure 9.17: Aerial imagery examples.

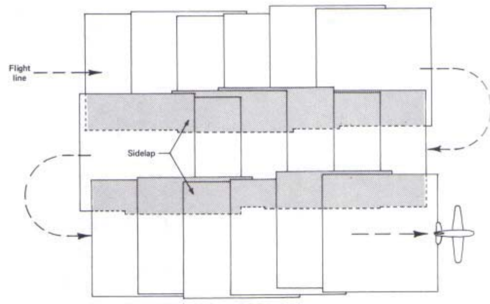


Figure 9.18: Aerial photgraphy flight pattern.

9.2.3.2 Operational use

Aerial photogrammetry is very useful in both supervision and survey missions. Imagery, despite being the oldest remote sensing type, is still important for wildfire management, and for pre-fire, active fire and post-fire assessment.

Supervision During a wildfire, some characteristics of the flame front can be deduced from aerial photography. In this phase of a firefighting mission, thermal imagery from the FLIR turret helps managers in tactical decisions. The techniques employed above an active fire can be divided into two branches. The first technique uses remote sensing optical and thermal imagery in combination, and it can accurately detect the burning areas. The second one uses only thermal imagery in order to estimate the spreading energy of a wildfire. This one is well explained in the FLIR turret section. For the first case, giving boundaries to an active fire is fundamental to circumscribe the wildfire and to determine the buffer area. In addition to instruments estimating fire thermal characteristics, other active fire characteristics can include assessment of trace gases within smoke plumes, which have important implications for regional air quality, and in situ assessment of fuel combusted. The assessment of such parameters ideally requires unfettered access and timely (i.e. rapid response) measurements, both of which are often impractical during wildfires owing to safety concerns. Remote locations of many fires make accessibility difficult. The application of remotely sensed optical and thermal imagery over large fires is a very important and necessary tool from the standpoint of both researches and land resource managers.[40]

Survey For surveying purposes, aerial imagery can be used both for pre-fire and post-fire operations. With LiDAR integration, aerial photogrammetry is used for pre-fire assessment, with this remote sensing fusion we are able to create a fuel map in three dimensions. We have explained the role of aerial photography for wildfire risk preparation in the previous paragraph, now we will analyze post-fire assessment with this type of tool.

post-fire The assessment of short- and long-term fire effects on local, regional, and global processes has been conducted using a wide range of in situ and remote methods. The application of remotely sensed imagery to monitor and assess the impacts of fire on local and regional environments can be broadly divided into:

- Burned area and perimeter methods; and
- Methods that assess a surface change (cover, fuel, etc.) caused by the fire.[40]

Mapping the burned area is the first thing to do after a fire. In this way, the area can be identified and any damage can be estimated. Using a bird's-eye view offers advantages in controlling the area and in monitoring it through time. Scanning the burned area with an airborne sensor tool permit to capture the heterogeneity and patchiness of fires and fire effects[40]. Yet field fire perimeter maps will remain important not only for validation purposes, but when atmosphere is too cloudy or smoky (a problem minimized using infrared imagery) to obtain useable imagery, and when remotely sensed data is not available when needed.[40] False-color or color infrared photography are often used in firefighting in order to collect imagery intelligence for scientific purposes. This allows us to combine the visible and the near infrared regions of the electromagnetic spectrum. Other characteristics that we can extrapolate from aerial photography in post-fire assessment are:

- Change in soil color;
- Soil infiltration and hydrophobicity;
- Change in vegetation char and ash cover;
- Amount of canopy scorch;

- Tree scarring; and
- Organic fuel consumption.

These data and the satellite survey of a wildfire area after the extinguishing operations are useful to monitor the reforestation progress and the changes in the physical characteristics of the soil.

Figure 9.19: Near infrared photography for burned surface analysis.

9.2.4 Synthetic aperture radar

9.2.4.1 Description

RADAR is an acronym for Radio Detection And Ranging. Radar works like a flash camera but at radio frequency. Typical radar system consists of transmitter, switch, antenna, receiver and data recorder. The transmitter generates a high power of electromagnetic pulse to antenna and returned echo to receiver. The antenna transmitted the EM pulse towards the area to be imaged and collects returned echoes. The returned signal is converted to digital number by the receiver and the function of the data recorder is to store data values for later processing and display. The radar platform flies along the track direction at constant velocity. For real array imaging radar, its long antenna produces a fan beam illuminating the ground below. The along track resolution is determined by the beamwidth while across resolution is determined by the pulse length. The larger antenna, the finer the detail the radar can solve.[56]

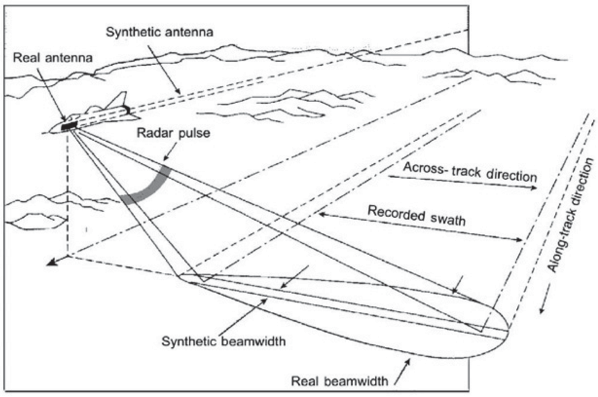


Figure 9.20: Airborne SAR functioning principle.

In SAR, forward motion of actual antenna is used to 'synthetize' a very long antenna. At each position a pulse is transmitted, the return echoes pass through the receiver and recorder in an 'echo store'. The Doppler frequency variation for each point on the ground is unique signature. SAR processing involves matching the Doppler frequency variations and demodulating by adjusting the frequency variation in the return echoes from each point on the ground. Result of this matched filter is a high-resolution image.[56] In the following figure we can see the main parts of a SAR system.

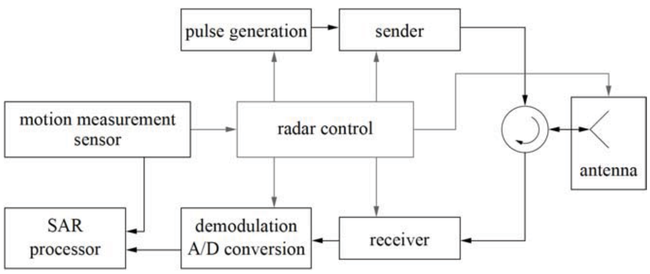


Figure 9.21: Basic block diagram of typical SAR system.

A pulse generation unit creates pulses with a bandwidth according to the aspired range resolution. They will be amplified by the sender and are transferred to the antenna via a circulator. The receiver gets the antenna output signal (echoes of the scene) amplifies them to an appropriate level and applies a band pass filter. After the demodulation and A/D conversion of the signals the SAR processor starts to calculate the SAR image. Additional motion information will be provided by a motion measurement system. A radar control unit arranges the operation sequence, particularly the time schedule.[56] SAR radar imagery is a good tool for topographic surveys and environmental tasks. Used mainly in space-based platforms, it is used aboard aircraft in order to monitor and patrol.

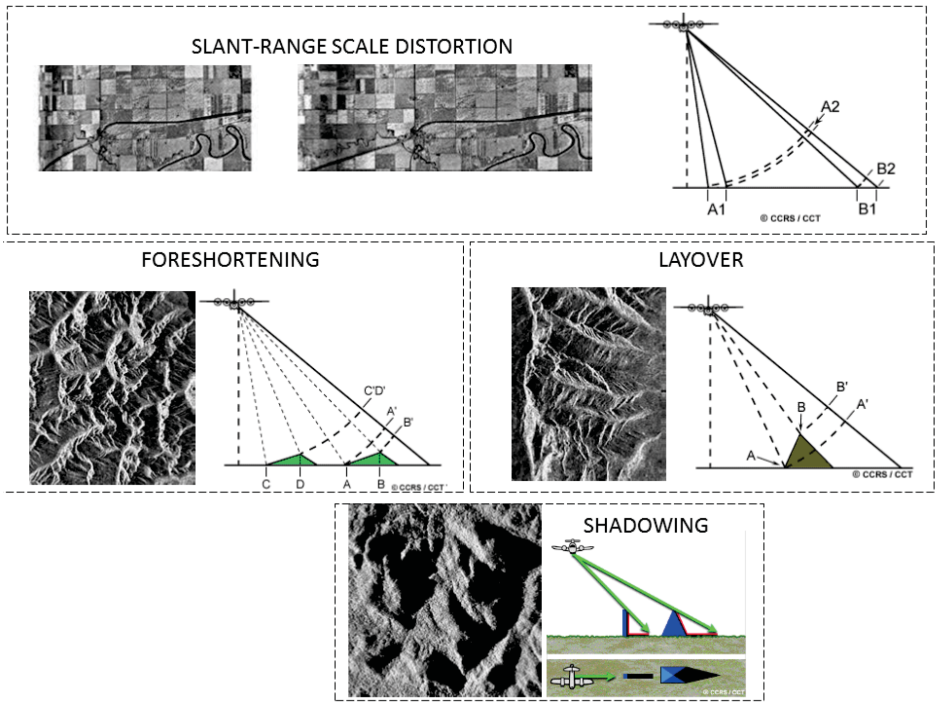


Figure 9.22: SAR ground errors.

9.2.4.2 Operational use

Radar remote sensing is an active sensor, used mostly for ecological processes and in areas where the weather is extensively cloudy or smoky.

Survey SAR is used in pre-fire and post-fire phases. Thanks to its resolution properties, it helps aerial photography and LiDAR to estimate the forest fuel load. Synthetic Aperture Radar is widely used for monitoring vegetation regrowth and soil moisture. Radar backscatter measurements over forested areas depend on:

- Vegetation type, species and structure;[54]
- Vegetation biomass;[54]
- Topography and surface roughness and canopy height;[54]
- Flooding and the presence/absence of standing water;[54]
- Moisture.[54]

Three sources of moisture variation may contribute to the forest radar backscatter: the forest floor, the canopy (including its woody elements) and the environmental conditions (rain events).[54]

Figure 9.23: SAR imagery of a wildfire.

pre-fire Another active sensor is also used to determine fuel loads in a forest, and this is SAR. The canopy fuel characteristics that define the most important variables for predicting fire hazard and behavior cannot be readily derived from the spectral information of passive optical sensors. In recent years, there has been an increasing emphasis to use active remote sensing data such as radar and LiDAR sensors to estimate various components of forest structure such as crown and stem biomass, foliage water content, crown bulk density and forest height that cha be directly incorporated into fire spread models and prediction.[57]

The SAR systems operate at different frequency bands and the radar signatures from forest vary with the used wavelength. This is in part due to the fact that he longer is wavelength is, the larger is the penetration of the forest canopy. The polarization of the radar signal is also important because different polarization of the radar signal is also important because different polarizations are sensitive to different orientations of the tree and forest structures, consisting of tree and forest specific spatial arrangements of stems, branches, twigs and leaves or needles.[58] Estimation of crown fuel variables can be obtained by using radar sensors operating at microwave frequencies with their polarimetric or interferometric measurements of forest biomass components and height. Radar measurements, particularly at low frequencies (400-1500 MHz), are sensitive to crown and stem biomass and moisture content as direct measurements of biomass and structure. Radar interferometric measurements are capable of providing forest height that can be readily transformed to fuel loads when combined with allometric equations available for different forests types. More importantly, radar is not sensitive to visibility conditions and can be obtained day or night and through smoke and cloud cover.[57] Radar sensing, used in integration with LiDAR and aerial imagery, could give a good resolution in mapping forest areas, with accurate data obtained through sensor fusion. It allows us have a better resolution output and to give managers a powerful tool of estimation of fire danger and a strategic and tactical advantage in extinguishing operations.

Figure 9.24: Surroundings of Rochambeau Airport, French Guyana. The green color indicates a ”depolarization” of the incident wave back-scattered by the medium, which is greater the denser the vegetation.[59]

post-fire Several studies have been carried out about using radar techniques to map burned areas and estimate forest regrowth, but SAR is a good way to monitor areas destroyed by wildfires, together with aerial photography. When fires burn healthy vegetation, they induce a significant drop in the spectral reflectance of this vegetation in the near-infrared spectrum and additional changes in the optical and mid-infrared spectra. These changes in reflectance are easily detected when comparison of the pre-fire and post-fire scenes is performed; changes in backscatter between pre-fire and post-fire imagery is also detectable when using Synthetic Aperture Radar imagery.[58]

In terms of rapid response wildfire:

- Airborne or satellite polarimetric SAR technologies will have distinct operational advantage over optical remote sensing techniques where persistent clouds, ash or smoke obscure the terrain during and after large conflagrations; and[60]

- Detailed surface cover maps showing the distribution of tree damage can be obtainedquickly from a single acquisition of C-, L- and P- band polarmietry and analyzed.[60]

9.3 Conclusions

This remote sensing suite is one of the best mixes that we can achieve in order to have good results in terms of:

- Fire description;
- Rapid response; and
- Multirole capability.

Obviously, the sensor tool choice has not been conceived for firefighting missions only, but also for other missions, such as environment surveys, disaster management coordination operations and search and rescue missions. In this way, the costs arising from aircraft usage can be justified by a multirole capability and by fast data collection in dangerous situations, where response time acquires a high degree of importance. In the next paragraph we will explain in which missions this sensor suite can be used and how the aid can be integrated with a command station mounted on a flying platform.

Chapter 10

COMMAND STATION

10.1 Introduction

In the previous chapter, we have illustrated the duties of a new figure in a command and control role in a forest fire scenario (COA). The COA should be supported by tactical information collected by the sensors installed on the platform, and the remote sensing suite must be operated by another figure, called TACO (TACtical Operator). The synergism between these two roles would be a big improvement in helping incident managers working on the forest fire scene. In a patrol aircraft, the sensors' output is displayed on the screen mounted on a command station. This tool helps TACO and COA visualize sensing imagery and control sensors in order to make use of them for the mission requirements.

10.2 Control station architecture and sensor integration

The tactical workstation must collect data from remote sensing tools and from aircraft avionics. This integrated system consists of three main layers, where fusion is possible by using the workstation as a collector of information. These tier are defined as:

- Cabin and avionics;
- Aircraft remote;
- Console.

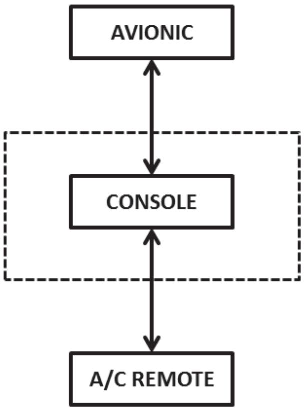


Figure 10.1: Block diagram of layers connection.

The central part of the tactical workstation is the console, which centralizes and displays all the information used in missions. Avionics and aircraft remote do not communicate with each other and they are separated by the console unit. We will now analyze every tier of the system.

10.2.1 Aircraft remote

This part of the control system is composed of all the sensors described in the previous chapter used for firefighting missions. Generally the sensing suite is modular, which means the sensors can be swapped easily in relation to the platform being used for the mission, if the platform itself is able to accommodate the chosen remote sensing suite.

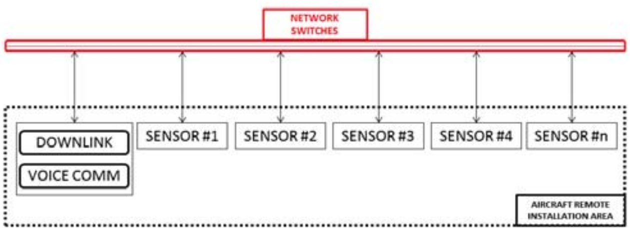


Figure 10.2: Generalized block diagram of aircraft remote layer.

In this layer there are the data link and voice communication devices, used for communication between airplane and ground stations. Downlink satellite communication is used for heavy data, report and image exchange. A secondary downlink device acting in both upload and download modes is used to send information to ground stations or to the incident commander in charge of the fire scene and to receive new mission details or information. All the devices must be connected to a network switch able to connect every tool installed aboard to the relative control features. The configuration of the aircraft remote installation area in the spotter aircraft for the forest fire case will have the four sensors chosen for the firefighting missions and the communication box. For this type of mission, the communication box acquires a high importance, as its aim is to accelerate communication times of sensible data.

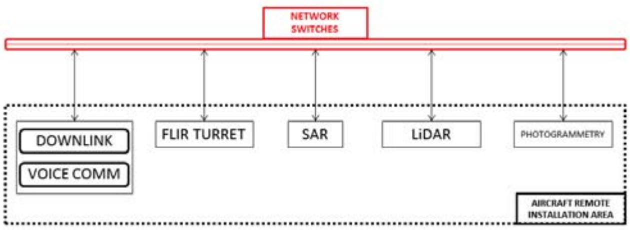


Figure 10.3: Aircraft remote block diagram customized for firefighting spotter aircraft.

10.2.2 Cabin and avionics

At this level, some information is obtained by the avionics suite installed aboard the airplane.

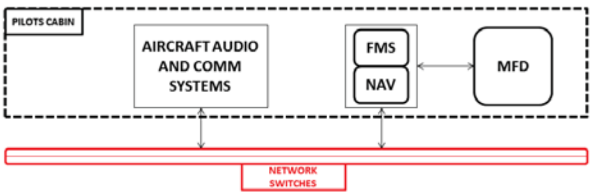


Figure 10.4: Avionic tier block diagram.

We can distinguish two blocks, the first is related to the communication and audio system of the cabin. It handles communications between flight crew, cabin crew and external agencies, in our case incident commander and other aircraft acting in the fire scenario. It differs from the downlink and communication of the aircraft installation tier because this tool is based on VHF frequency, while the other one is based on satellite communications. For the type of mission that we have to carry out, the communication system is composed of 4 VHF channels, two dedicated to navigation and two dedicated to the cabin crew. All the aerial resources working on a fire must be coordinated on one frequency.

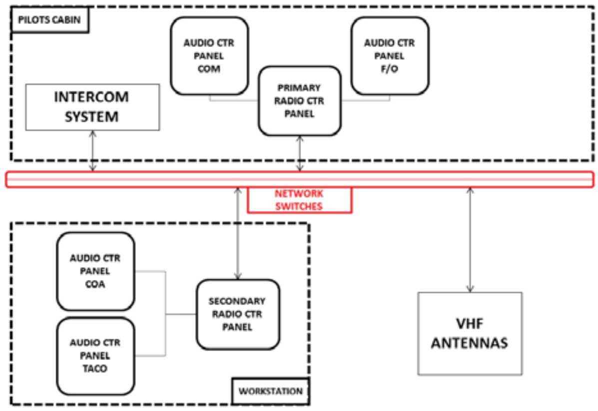


Figure 10.5: Communications block diagram.

The second block connected to the network switch is intrinsic to the aircraft navigation control system, which is used for the information coming from the IMU and GPS devices. The workstation integrates this information in the process which takes place between GPS, GIS and remote sensing, explained in the previous chapter. The FMS block refers to the Flight Management System, which is composed of Flight Management Computer (FMC), Control Display Unit (CDU) and other external inputs from engines, navigation system and data storage.

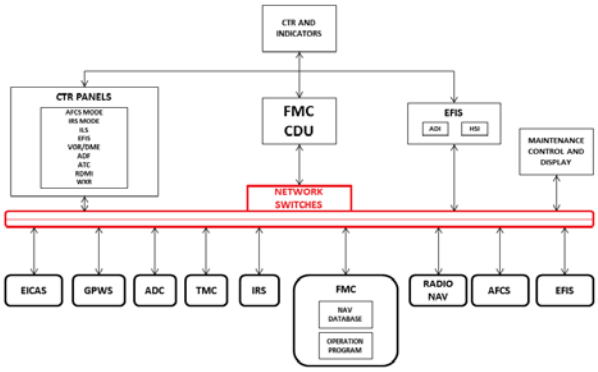


Figure 10.6: Flight management system block diagram.

Obviously all the information managed by FMS is displayed on the MFD (Multi-Functional Display) installed in the cockpit, for an easy comprehension and a rapid utilization of the data shown. The TCAS II device informs the COA in firefighting operations, and in the block diagram it is considered to be in the RADIONAV block.

10.2.3 Tactical console

This structural level is composed mainly of the workstation, positioned behind the flight crew and operated by TACO. The COA will not be in charge of operating the devices connected to the workstation, but he will have two screens where the information is passively repeated, he will have the possibility to communicate with the crew aboard the aircraft and he will also have external resources, like other aircraft participating in the mission and the DOS/ROS on the scene. The workstation will have two screens, one dedicated to the sensor in use, and the other one dedicated to the mission information. Displays will be of a different sizes, the smaller one is for the sensor and the bigger one is for the mission control module. The command station will be equipped with a joystick that can move the FLIR turret gimbal, and a pointer to work on the cartographic mission scene, for all operational needs. Information from the mission control module can be repeated on the pilots' MFD, and the mission control module will also communicate with the FMS in order to have a common and uniform mission path, so as to avoid misunderstandings between operative and flight crews. Data storage is fundamental for a record of the mission and for a straightforward debriefing of the information acquired during the operative mission. The same data could also be sent to the management centers for a quick update via satcom devices. It is advisable to have the satcom connection working both in upload and download modes, in order to send information primarily, but also to receive datasets for new missions without a forced base return.

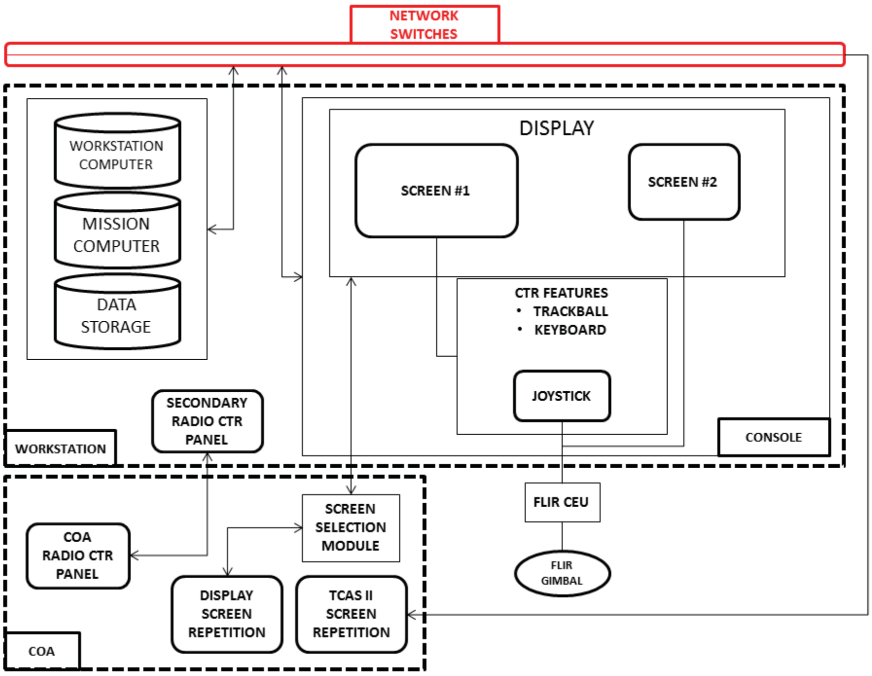


Figure 10.7: Tactical console block diagram.

The FLIR gimbal is controlled via a Control Electronic Unit, which transforms the joystick's analogic inputs into digital outputs and consequently into the FLIR turret movement. During operations, being able to move the FLIR turret is vital. When the aircraft is in control of the situation and is following an orbiting flight path above the wildfire, the FLIR turret is manoeuvred by the TACO, so as to ensure that he has the best view of the fire.

It does become necessary to identify and track specific targets, of course, especially when evaluating drop effectiveness, observing changing in fire behaviour, or precisely identifying a specific problem area. This is most readily accomplished while in orbit and direct mode, and from an altitude that gives an overall perspective on the situation. When using the FLIR in this manner, precise control is required and significant concentration unavoidable. Practice is mandatory, and with experience comes fluidity. Yet even in this context, there exists a technique which allow an essentially "heads-up" approach to the task, and again it is the aircraft which becomes the primary aiming agent within the system. When establishing an orbit with respect to some relevant context, if the sensor is aimed between 45 and 60 degrees of azimuth and 15 to 20 degrees below the horizontal, then the orbit on the aircraft can be maintained in such a manner that the relevant image remains in the center of the monitor and slowly rotates. This enables sustained observation of the chosen target without requiring much more than occasional control input, while the pilot flies the requisite number of orbits in a consistent attitude. Both the pilot and the air attack officer can see the monitor in most situations, and again it is used as simply another flight instrument which is frequently scanned rather than focused upon. There are certainly situations encountered that require sustained focused concentration on the system monitor; scanning for hot spots in burnt windrows, for example. This orbiting technique is optimal in this context and allows sustained target observation from a safe altitude. Very acceptable results can be expected when scanning windrows from altitudes of 2000 feet A.G.L. because of the image stability provided through using the equipment in this manner.[45]In order to meet his operative requirements, the COA will be able to choose which of the two VHF channels to use. Although the command and the information given to the aerial resources by the COA occupy only one VHF channel, one channel is used for backup purposes. Another feature used by the COA is the switch used to change the screen repetition, aimed at optimizing the use of the information collected by the remote sensing suite. The other screen installed in front of the COA shows the information provided by the TCAS II device.

TCAS II TCAS is a family of airborne devices that function independently of the ground-based air traffic control (ATC) system, and provide collision avoidance protection for a broad spectrum of aircraft types. All TCAS systems provide some degree of collision threat alerting, and a traffic display. TCAS I and II differ primarily by their alerting capability. TCAS I provides traffic advisories (TAs) to assist the pilot in the visual acquisition of intruder aircraft. TCAS I is mandated for use in the U.S. for turbine powered, passenger-carrying aircraft having more than 10 and less than 31 seats. TCAS I is also installed on a number of general aviation fixed-wing aircraft and helicopters. TCAS II provides TAs and resolution advisories (RAs), i.e., recommended escape maneuvers, in the vertical dimension to either increase or maintain the existing vertical separation between aircraft. TCAS II is mandated by the U.S. for commercial aircraft, including regional airline aircraft with more than 30 seats or a maximum takeoff weight greater than 33,000 lbs. Although not mandated for general aviation use, many turbine-powered general aviation aircraft and some helicopters are also equipped with TCAS II. The TCAS concept makes use of the same radar beacon transponders installed on aircraft to operate with ATC's ground-based radars. The level of protection provided by TCAS equipment depends on the type of transponder the target aircraft is carrying. It should be noted that TCAS provides no protection against aircraft that do not have an operating transponder.[61]

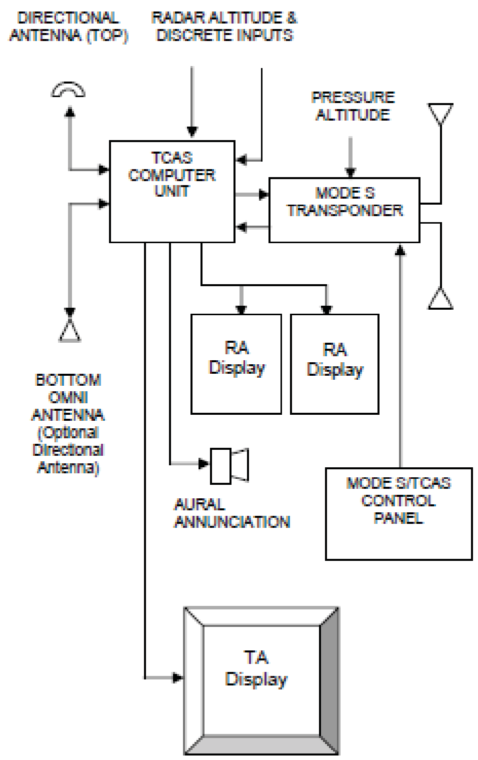


Figure 10.8: TCAS II block diagram example.

TCAS II could also be used as control aid aimed at helping the COA to identify any air traffic approaching the restricted airspace above the forest fire.

Because the spotter aircraft is circling above the wildfire and its alert system has different range performances, we can see that this is the safest way to locate possible intruders.

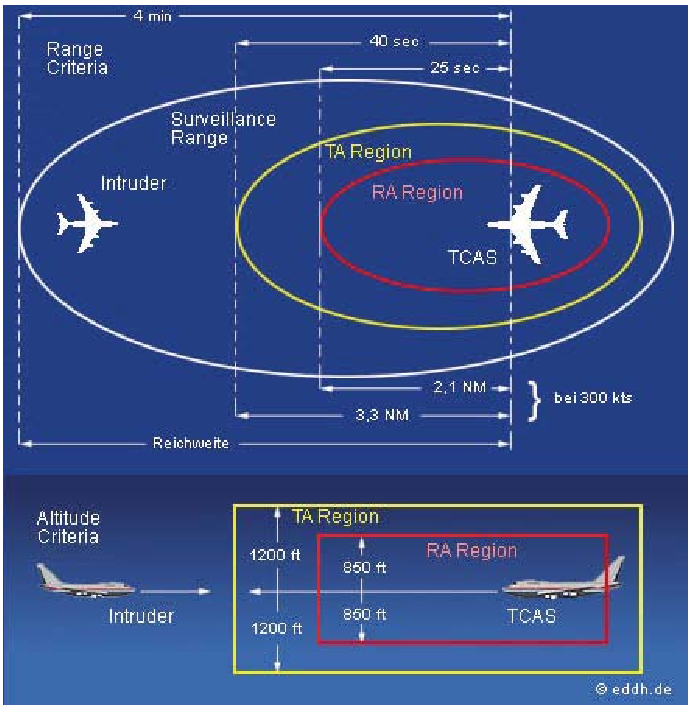


Figure 10.9: Functioning criteria of TCAS II.

Figure 10.10: TCAS II display example.

10.2.4 Command station overview

For a better comprehension of the problem, an overall view is proposed, with a fusion and a simplification of the three layers.

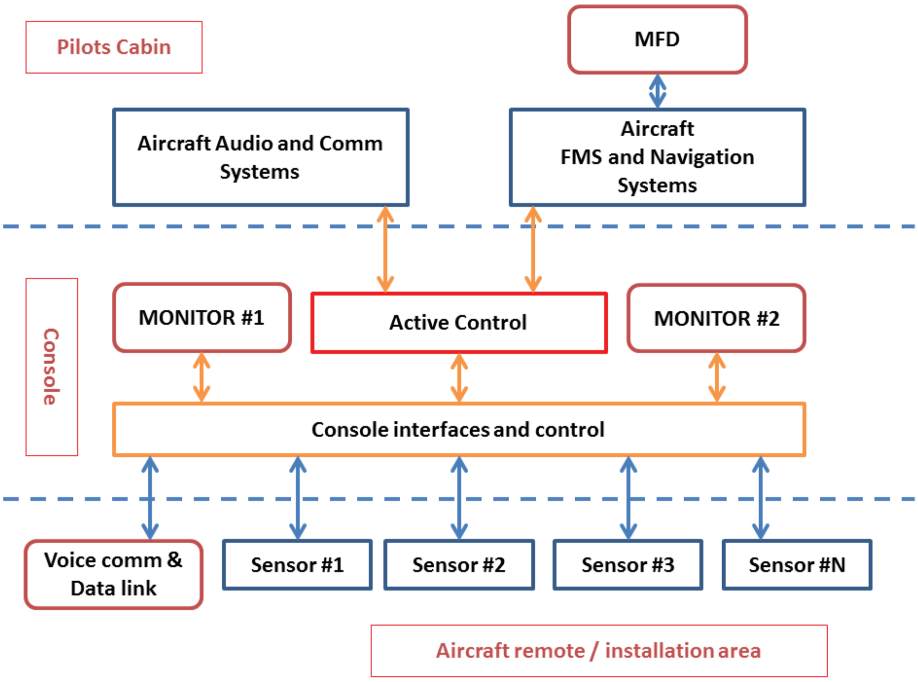


Figure 10.11: Command station integration overview.

10.3 Utilization modes, a description

The Command Station could be used in three main modes, in relation to which type of mission we are carrying out. Missions are related to disaster managing and environmental control, in particular there are three types of missions:

- Active control;
- Survey;
- Search and rescue.

We will explain every mission type in detail and which data are useful to the tactical crew.

10.3.1 Active control mode

The missions accomplished in Active Control mode are mostly for firefighting purposes. In relation to the previous chapter, we can consider patrol and survey missions as active mode missions. The presence of a cartographic tool will be fundamental, in order to provide more information about the topography and more advice for the aircraft about to drop their payloads over the flames. Another useful tool is the Drop Master Switch, which needs to be installed on the water bomber or helicopter involved in the firefighting operation. When the aircraft have dropped their payload, this tool sends a signal to the spotter aircraft, so that the precise location where the payload was dropped will appear on the spotter aircraft's cartographic screen.

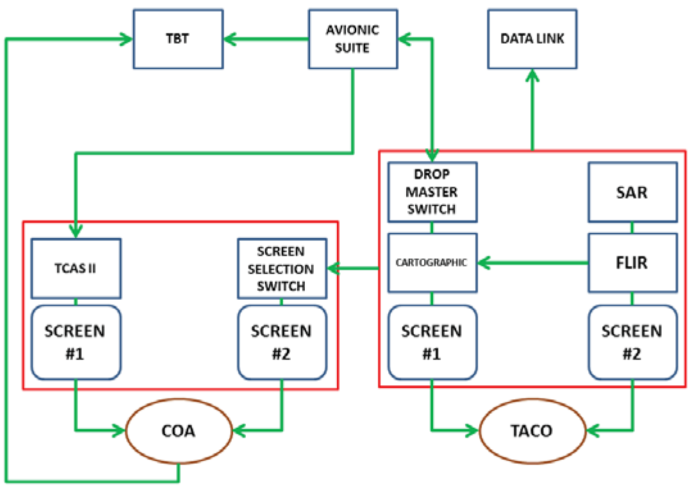


Figure 10.12: Active control mode logic.

The information showed is different for the two tactical crews. We will now analyze the COA and TACO workspace, in order to understand the subtle differences between the two roles.

COA The COA is in direct contact with the DOS/ROS during the firefighting operation, and he determines the appropriate tactics for the aerial resources. He is also in contact with the flying crew operating in the suppression area. The COA has two devices, radio and screens. The radio has two dedicated channels in order to communicate with the operating traffic and with the DOS/ROS commander. Communication in the aircraft is carried out via an intercommunication device. It is important to have clear communications between the COA and the TACO, who will need to exchange information about maneuvering sensors. Two screens are used, which passively repeat information. The first screen shows information about inbound traffic and operating traffic, because the TCAS II functioning principle is based on transponder utilization. This tool is mostly used to provide aid in separating BAT traffic and any intruder equipped with a transponder. The ultimate responsibility of aircraft separation, in VFR flights, lies with the pilot in command of operating traffic. The second screen is equipped with a switch, and the COA can select which information is more useful in any given circumstance. He can decide to display images from the remote sensing suite, in this case FLIR turret imagery, or an overview of the situation, with cartographic reporting of the dropping point.

TACO This operative role is completely under the command of the COA in this operation. He must command remote sensing tools in order to acquire the best possible data for the tactical and strategic decisions taken by the managers. He is responsible for data acquisition and for the remote sensing suite. He gives advice to the COA in case of emergency situations or danger to the flight safety of the entire operation. The Active Control mode is the best choice in order to have the best information in a faster way. Rapidity is the key to extinguish wildfire quickly, so as to avoid considerable damage to the landscape and environment. This mode could also be used in other missions, not only for firefighting, but for any type of situation involving disaster management.

10.3.2 Survey mode

This mode is used both for firefighting and for topographic and cadastral purposes. It is based mostly on three sensors, namely Synthetic Aperture Radar, LiDAR and Aerial Imagery. In a firefighting context, this mode could be used for pre-fire and post-fire assessments, which are very important in environment studies and fire risk prediction. The mission can be accomplished only by a

TACO, without the help of a COA. This is because there is only one collection of information and intelligence, and one operator can supervise all the remote sensing suite alone.

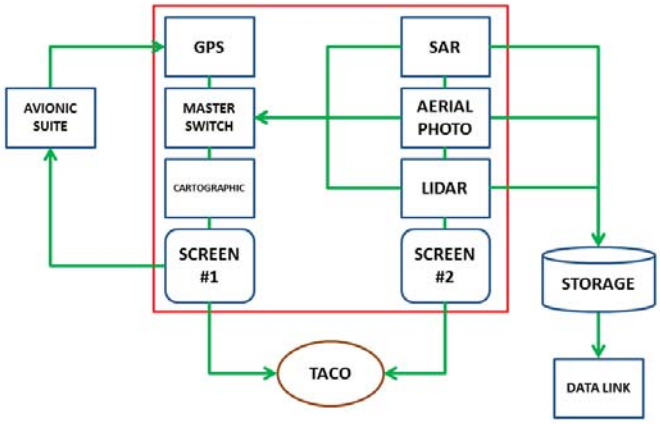


Figure 10.13: Survey mode logic.

The TACO has two screens, and like in the previous mode, one is dedicated to the global view and one to the sensor being used. The first screen displays mission information, integrating GPS data with cartographic data uploaded in the database, so as to obtain an overall view of the mission. Everything is integrated with a master switch, which is handled by the TACO and used to set and highlight the reference points during the survey mission. The avionics suite is essential for the accomplishment of the mission, it supplies GPS data and provides the pilot with information for flight management and the progress of the operations through the MFD. Remote sensing data is shown on the second screen, and the operator can select which information can be displayed. All the collected data are stored on an external hard drive, and can be downloaded at the end of the mission. The operator may also decide to send images and data that he considers a priority via data link.

10.3.3 Search and rescue mode

The last mode concerns SAR actions and patrol missions. The sensor mix can be used for easy search and rescue and patrol missions, where both tactical operators (COA and TACO) are present. Synthetic Aperture Radar and FLIR turret are two devices commonly used in this type of mission.

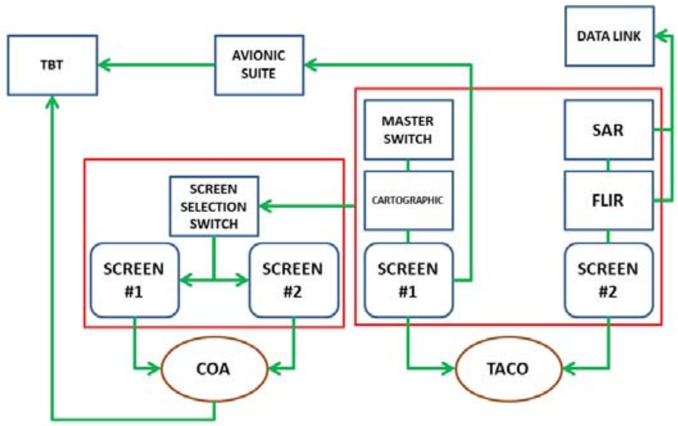


Figure 10.14: SAR mode logic.

The COA acts as an observer in SAR missions, helped by the two screens that display passively the TACO monitors. He remains the coordinator of the aerial teams and is in communication with ground bases or other aerial resources in the area. The avionics suite installed onboard provides the basic information for the cartographic device, and the flying crew have the repetition of the first TACO screen with the search itinerary and information about the search pattern and possible course alteration. The second screen is used by the TACO for supervising and managing the remote sensing suite. The sensors in use are the synthetic aperture radar, which is often used in search and rescue missions and boundary patrols, and the moving FLIR turret, which can be useful for surveillance purposes.

Chapter 11

AIRCRAFT INTEGRATION

11.1 Choice of platform

In this section, we will describe possible platforms for the integration of the Remote Sensing suite previously described. In order to do this, we need to set some design and performance parameters, which are linked to mission type requirements and aircraft availability in Italy. The integration of the new role of spotter aircraft in wildfire fighting missions in Italy represents a critical part in the choice of a platform. Considering the current financial and economic crisis, choosing the appropriate aircraft is a fundamental part in this discussion. Another factor to consider is the re-use of existing airplanes, following the trend of adapting existing aircraft to be suitable for firefighting roles, in order to make them suitable to complete new or similar missions. The role of a Bird Dog aircraft is comparable to the roles of a military AWACS or of a patrol mission aircraft. Once the right platform for integration has been identified following some basic requirements, we will be able to start studying the weight limits and the positioning of the Remote Sensing suite and of the flight crew.

11.1.1 Requirements

We can categorize requirements in aircraft configuration and field performance. The first concerns aircraft architecture and design concept, while the second is about the best choice in terms of aircraft performance during the mission. The key concepts of aircraft design are essentially three:

- Wing and fuselage mutual vertical position;

- Engine type;
- Cabin dimension.

The aircraft performance during missions is related to flight mechanics, and the basic principles are:

- Takeoff and landing capabilities;
- Range and endurance performances.

These five points describe the basic requirements of the type of platform to adopt in order to introduce a new Bird Dog aircraft in the Italian wildfire fighting system.

11.1.1.1 Aircraft design

Wing vertical position The wing vertical location with respect to the fuselage id generally set by the real-world environment in which the aircraft will operate.[62] Considering a firefighting mission as the defining type of mission, we must analyze the flight path followed by the aircraft during the command and control phase. The COA must have the possibility to have a clear visual field of the ground, in order to have the operation area in sight. The spotter aircraft maintains an orbital path flying with a gentle turn, in order to have the best results in remote sensing thermal imagery (the FLIR turret utilization parameters for this type of mission are known from its operative manual). The space occupied by the Remote Sensing suite and by the TACO workstation in the cabin is not to be underestimated, and clearance between all the single sensors systems must be correctly evaluated in order to facilitate routine and special maintenance. For firefighting operations, spotter aircraft must be able to take off and land on unimproved fields. In emergency situations, the aircraft could use grass airstrips and other airfields, in order to increase its operative flexibility. Airfields are often short grassy runways, so a STOL capability is a desirable quality. The following table draws a comparison between the three wing vertical configuration solutions for an airplane in relation to its operative characteristics. The number 1 means ‘preferred’ and the number 3 means ‘last preferred’.[63]

	HIGH WING	MID WING	LOW WING
INTERFERENCE DRAG	2	1	3
LATERAL STABILITY	1	2	3
VISIBILITY FROM CABIN*	1	2	3
LANDING GEAR WEIGHT	3**	2	1

*=Strongly dependent on where the wing passes through the fuselage.
**=If the gear is retracted into the fuselage, gear weight is not necessarily a factor. In that case the landing gear often requires a 'bump fairing' which causes additional drag.

Table 11.1: Choose criteria between the three possible vertical position of wing.[63]

In order to satisfy these operative requirements, the best choice would be a high winged platform.

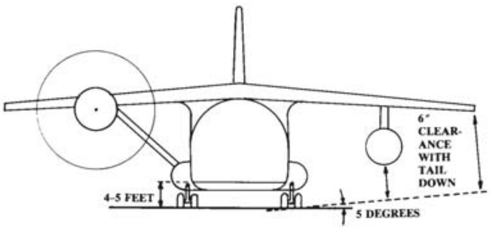


Figure 11.1: High wing configuration layout example.

The major benefit of a high wing is that it allows placing the fuselage closer to the ground. With a high wing, jet engines or propellers will have sufficient ground clearance without excessive landing-gear length. Also, the wing tips of a swept high wing are not as likely to strike the ground when in a nose-high, rolled attitude. For these reasons, landing-gear weight is generally reduced for a high-wing aircraft. For low-speed aircraft, external struts can be used to greatly lower wing weight. However, external struts add substantially to the drag. Since roughly two thirds of the lift is contributed by the upper surface of the wing, it follows that less drag impact will be seen if the strut disturbs the airflow on the lower surface of the wing that if the strut is above the wing, as would be necessary for a strut-brace, low wing. Another structural benefit occurs if the wing box is carried over the top of the fuselage rather than passing through it. When the wing box passes through the fuselage, the fuselage must be stiffened around the cut-out area. This adds weight to the fuselage. However, passing the wing box over the fuselage will increase drag due to the increase in frontal area. For an aircraft designed with short takeoff and landing (STOL) requirements, a high wing offers several advantages. The high position allow a room for the very large wing flaps needed for a high lift coefficient. The height of the wing above the ground tends to prevent "floating", where the ground effect increases lift as the aircraft approaches the ground. A floating tendency makes it difficult to touch down on the desired spot. Finally, most STOL designs are also intended to operate from unimproved fields. A high wing places the engines and propellers away from flying rocks and debris.[63]

Engine type The selection of the power plant follows mission type criteria. There are several factors influencing the selection of the engine and they are mostly connected to operative choices. The selection of the propulsion systems follow three decisions:

- Type of engine;
- Number of engine; and
- Engine layout.

In relation to the selection of the type of engine we must consider the field of utilization of the airplane and the operating altitude of flight missions. The flight envelope (speed-altitude envelope) of an airplane has an important bearing on the choice of the type of propulsion system.[63]

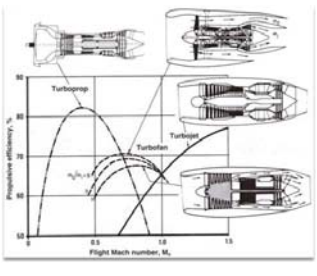


Figure 11.2: Aeronautical engines typical utilization range.

Spotter aircraft operations are carried out at subsonic speeds, at a relative low altitude in almost all missions that the Bird Dog can carry out (patrol, surveillance and survey), between 2000 feet AGL (when it is in a command and control situation) and 5000 feet AGL (every sensor has an optimum altitude in relation to the type of mission). 5000 feet AGL is the optimum altitude of the Remote Sensing suite.

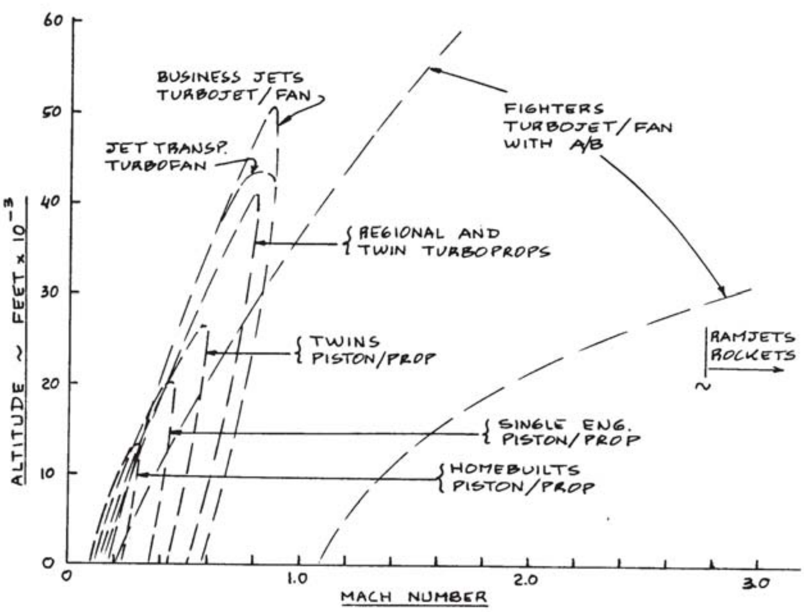


Figure 11.3: Engine range of use in relation to altitude.

Considering as a limit the Mach number of 0.6/0.7, there are three types of propulsion systems to take into consideration:

- Piston/propeller with or without supercharging;
- Turbo/propeller; and
- Propfan.

In relation to operative altitude, operative speed and propulsion efficiency, the best choice is a turbo propelled platform. The number of engines is not a crucial factor, but for an overall flight safety it is better to have a twin propelled aircraft. We will now focus the discussion on the installation position of the propeller on the best platform for the new firefighting role we proposed. We can have two types of location, tractor or pusher propeller. A tractor installation has the propeller in front of its attachment point (usually the motor). A pusher location has the propeller behind the attachment point.

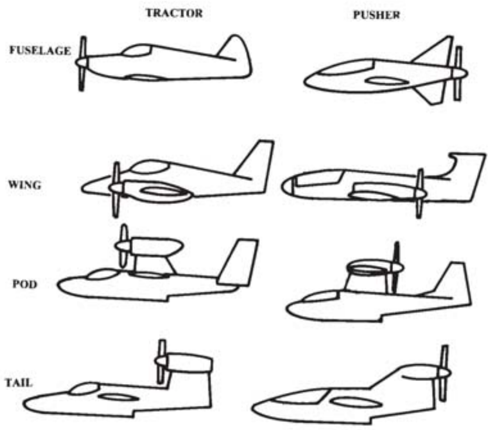


Figure 11.4: Propeller engine types of installation.

A twin engine aircraft often has a tractor installation, but in our case we can find some advantages in installing a pusher propeller system. The pusher propeller reduces cabin noise because the engine exhaust is pointed away from the cabin, and because the windscreen isn't buffeted by propwash. Also, the pusher arrangement usually improves the pilot's outside vision.[62] For our requirements of ground visibility, the pusher propeller installation would be ideal, together with a high wing installation.

Internal dimensions Cabin sizing is proportional to the mission we need to accomplish. The crew onboard the airplane is composed of four people:

- Commander;
- First Officer;
- COA; and
- TACO.

We can now consider the patrol aircraft currently used by the major military aviation fleets worldwide and the aircraft used for our missions in the countries considered in the first part of this thesis.

MODEL	COUNTRY	MTOW	NOTE
OV-10A "Bronco"	USA	6552 kg	High-wing twin-engine
Beechcraft King Air 200	USA; FRANCE	5670 kg	Low-wing twin-engine
AH-1 Firewatch "Cobra"	USA	4500 kg	Helicopter
GippsAero GA8 Airvan	AUSTRALIA	1814 kg	High-wing mono-engine
Aérospatiale AS 350 Écureuil	AUSTRALIA	2250 kg	Helicopter
Beechcraft Baron 55	CANADA	1431 kg	Low-wing twin-engine
TC 690 (Turbo Commander)	CANADA	4683 kg	High-wing twin-engine
Cessna 337 Skymaster	CANADA	2100 kg	High-wing twin-engine

Table 11.2: Spotter airplanes used in countries analyzed in first part of thesis.

Another consideration was about the space occupied by the workstation and the Remote Sensing suite. In this section, we must only consider cabin volume, where the workstation and the tactical crew are positioned, and where the sensors are installed. We also need to consider that some sensors could be installed in relative pods or nacelles with minor modifications of the structures. For example, the FLIR turret is often installed outside the cabin, whilst the aerial photography system could be installed in the underwing pylons. Combining this information and considering the Bird Dog aircraft used in other countries (excluding helicopters), we can see a common thread in the construction and design of the aircraft used in these missions. This is accompanied by the CS-23 construction regulations provided by EASA. In 'SUBPART A – GENERAL' of the EASA normative, the CS-23 regulation provides us with a general rule of applicability:

(a) The airworthiness code is applicable to –

(1) Aeroplanes in the normal utility and aerobatic categories that have a seating configuration, excluding the pilot seat(s), of nine or fewer and a maximum certificated take-off weight of 5670 kg (12500 lb) or less; and

(2) Propeller-driven twin-engined aeroplanes in the commuter category that have a seating configuration, excluding the pilot seat(s), of nineteen or fewer and a maximum certificated take-off weight of 8618 kg (19000 lb) or less.[64]

In relation to the previous subchapter, we are considering only high-winged planes in choosing the platform in which we will install an airborne tactical command station.

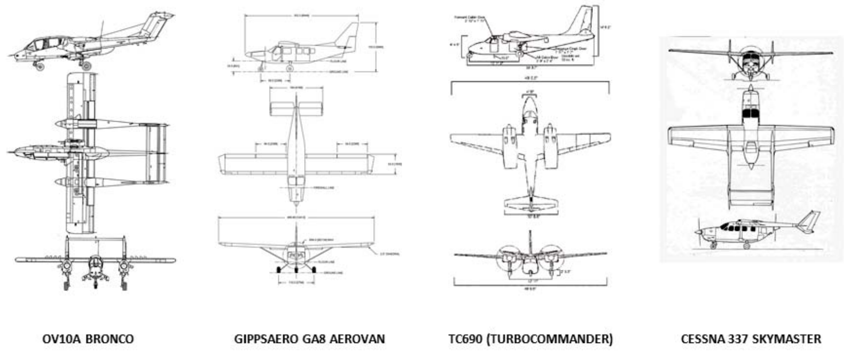


Figure 11.5: Aircraft used in comparison.

From these four platforms used in aerial firefighting worldwide we have selected the last three, because OV10A is difficult to source and is only a two-seat aircraft, undersized for our purposes. A common feature of the other three airplanes is the internal dimensions, as we can see there is enough space and volume to host an airborne Remote Sensing suite.

MODEL	LENGTH	HEIGHT	WIDTH	CREW	SEATS
GippsAero GA8 Airvan	4.01 mt	1.19 mt	1.27 mt	1	7
TurboCommander TC690	4.34 mt	1.36 mt	1.22 mt	2	4
Cessna 337 Skymaster	3.02 mt	1.3 mt	1.12 mt	2	4

Table 11.3: Principal dimensions of aircraft used in comparison.

In conclusion, we must find an aircraft of the same category as the aforementioned aircraft among the planes available in the Italian fleet for all the Armed Forces.

11.1.1.2 Aircraft performances

After the selection of an aircraft design, the platform must follow some simple performance requirements, in order to have the right airplane for the spotter role in firefighting.

Take off and landing capabilities The platform must be able to take off and land in emergency conditions, as in disaster management situations all the airfields near the affected zone could assume a higher strategic and tactical importance. The platform needs to be able to use all types of airfields and all existing runway pavement surfaces, from concrete to grass. The airplane must be able to operate from unimproved fields in order to achieve a better mission flexibility. A high-winged design and a pusher propeller can help with this requirement. Obviously the selection of STOL capability is recommended in order to be able to use short fields as well. Statistical analysis helps us in searching basic performance parameters for our platform.

MODEL	TAKE OFF DISTANCE 50FT	LANDING DISTANCE 50FT
GippsAero GA8 Airvan	549 m	366 m
TurboCommander TC690	689 m	482 m
Cessna 337 Skymaster	511 m	503 m

Table 11.4: Take off and landing performances.

Endurance Another substantial guideline in choosing a platform is endurance performance, which is strongly connected to the mission profile of the aerial resources involved in extinguishing operations above the flames. The reference aircraft is Canadair CL-415, mostly used in suppression activities and the only fixed-wing water bomber used in wildfire fighting missions. The data below are all statistically based and sum up the mean operation time of each aerial resource in Italy.

TYPE OF AIRCRAFT	WATER PAYLOAD	REFERENCE PERFORMANCES	
		MIX AIB mission endurance	Transfer Speed
CL-415	6,000 lt	3h	270 km/h
AB 412	800 lt	2h	220-160 km/h
ERICKSON S64 – E/F	9,000 lt	2h	180 km/h

Table 11.5: Italian fleet performances, mission endurance is based on statistical average on last year interventions.[65]

The defining criterion for endurance is three hours, so our platform must be able to endure this long over the flames during a firefighting mission. Using statistical data from the three airplanes identified in the previous subchapter, we can carry out a performance analysis of what we need to find in the Italian fleet.

MODEL	MAX ENDURANCE	SPEED
GippsAero GA8 Airvan	6h	104 kts
TurboCommander TC690	6h 48'	250 kts
Cessna 337 Skymaster	6h	169 kts

Table 11.6: Endurance and speed performances for aircraft used in comparison.

The endurance of a spotter aircraft must be higher compared to a water bomber. A typical mission involves finding the wildfire and directing aerial operations. So the endurance time is justified by the mission phases previously described.

11.1.1.3 Conclusions

A platform with the following characteristics needs to be found in the Italian Armed Forces fleet (these parameters have been derived by averaging values of the features of the various aircraft, and they are therefore indicative).

REQUIREMENTS		
WING		HIGH
ENGINE		PUSHER TURBOPROP
INTERNAL DIMENSIONS	LENGTH	~4 m
	WIDTH	~1,2 m
	HEIGHT	~1,2 m
CREW		2
SEAT		4~6
TAKE OFF DISTANCE 50FT		~600 m
LANDING DISTANCE 50 FT		~450 m
SPEED		~175 kts
ENDURANCE		~6 h

Table 11.7: Requirements summary.

The challenge is to find an ideal platform about to be retired from service for this type of mission according to availability in Italian fleet.

11.1.2 Italian aircraft availability

Considering the requirements for the ideal candidate, the availability of the machine is the most important factor. The tables below show the availability of aerial components in Transport and Special Mission operations.

ITALIAN AIR FORCE		
Type	**Active**	**Mission**
ATL-1 (MPA)	2	Special Mission
G222 (EW)	1	Special Mission
Gulfstream III (Recce)	1	Special Mission
C-27J	12	Transport
C-130J	16	Transport
G222	2	Transport
P180	17	Transport

Table 11.8: Transport and special mission aircraft used by Italian Air Force.[66]

ITALIAN ARMY		
Type	**Active**	**Mission**
Dornier 228	3	Transport
P180	3	Transport

Table 11.9: Transport aircraft used by Italian Army.[66]

ITALIAN NAVY		
Type	**Active**	**Mission**
P180	3	Transport

Table 11.10: Transport aircraft used by Italian Navy.[66]

ITALIAN COAST GUARD		
Type	**Active**	**Mission**
ATR 42 MP	7	Special Mission
P166 DL3/DP1	2	Special Mission
P180	1	Special Mission

Table 11.11: Special mission aircraft used by Italian Coast Guard.[67]

ITALIAN STATE POLICE		
Type	**Active**	**Mission**
Vulcanair P68 Observer	18	Patrol
P180	2	Special Mission

Table 11.12: Special mission aircraft used by Italian State Police.[68]

CARABINIERI		
Type	**Active**	**Mission**
P180	1	Special Mission

Table 11.13: Special mission aircraft used by Carabinieri.[69]

CORPO FORESTALE DELLO STATO		
Type	**Active**	**Mission**
P180	1	Special Mission

Table 11.14: Special mission aircraft used by *Corpo Forestale dello Stato*.[70]

GUARDIA DI FINANZA		
Type	**Active**	**Mission**
ATR 42 MP	4	Special Mission
P166 DL3/DP1	10	Special Mission
P180	2	Special Mission

Table 11.15: Special mission aircraft used by *Guardia di Finanza*.[71]

We can see two aircraft which are suitable for the firefighting spotter role and they are both produced by the Italian company Piaggio Aero. P180 Avanti II is an executive turbopropeller, used for executive missions of VIP transport and logistic operations. Its high speed makes it an excellent aerial resource for authorities' transportation and its relatively young age provides a reason for keeping it in this role. The cruise speed is also a factor in a patrol mission, which means that the P180 does not quite have the right requirements for the wildfire fighting role. The perfect balance between requirements and availability is represented by the Piaggio P.166. In terms of availability this is the best choice, because it is still operative whilst many others have been retired from operative service.

ITALIAN AIR FORCE	
P.166M	49
P.166BL2/APH	2
P.166-DL3/APH	6

Table 11.16: Number of P.166 used in Italian Air Force (2012 data).[72]

ITALIAN COAST GUARD	
P.166-DL3/SEM	12
P.166-DL3	2

Table 11.17: Number of P.166 used in Italian Coast Guard (2012 data).[72]

GUARDIA DI FINANZA	
P.166-DL3/SEM	10
P.166-DP1	2

Table 11.18: Number of P.166 used in *Guardia di Finanza* (2012 data).[72]

The following chapters are dedicated to the selection and comparison of the Piaggio P166 and the requirements needed for wildfire fighting spotter mission, to a presentation of the aircraft and to the integration of the Remote Sensing suite for firefighting purposes.

11.1.2.1 P.166 and spotter aircraft comparison

In order to justify the choice of the Piaggio P.166, a comparison must be drawn with other spotter aircraft with the same design used for firefighting purposes in other countries. Discriminating factors are:

- Payload and internal dimensions;
- Takeoff and landing performances; and
- Cruise speed and endurance.

All the aircraft are matched with their Maximum Takeoff Weight, we can note that all the aircraft used in this part of the discussion are under the limitations of 5670 kg imposed by the EASA CS-23 regulation.

Design and configuration The Piaggio P.166 matches all the design requirements because it has the following characteristics:

- High winged;
- Pusher twin engine;
- Used for patrol mission by the Armed Forces.

The gull wing of the Piaggio P166 came about because this airplane was derived from an amphibious airplane. Gull wings are often used in amphibious airplanes to keep the propeller out of the water spray from the hull. An advantage of the gull wing is that it provides a low interference intersection with the fuselage. A disadvantage is the structural discontinuity which adds weight to the wing.[63]This wing shape is beneficial for operations from unimproved fields, as it can protect the engine blade from debris and other objects and stones that could damage the power plants.

Figure 11.6: Gull wing examples.

Payload Availability was the first factor to take into account in the aircraft selection. The second one is the payload weight, in order to determine whether the aircraft will be able to sustain the weight of the sensors which need to be installed, which is also a factor in determining whether the reconversion project is feasible. In order to have comparable data and obtain the payload weight we have used the following formula:

$$W_{to} = W_{oe} + W_f + W_{pl}$$

Where the terms are defined:

- W_{to} is take-off gross weight;
- W_{oe} is operating empty weight;
- W_f is mission fuel weight; and
- W_{pl} is payload weight.

W_{to} is also known as Maximum Take-off Weight (MTOW), which will be used in our comparison. n the next table we have summarized all the weight components for the four aircraft used in the comparison. The Payload Weight was obtained using data from *Jane's All the World's Aircraft*.

MODEL	MTOW	OPERATING EMPTY WEIGHT	FUEL WEIGHT	PAYLOAD WEIGHT
PIAGGIO P.166	4500 kg	2853 kg	1130 kg	517 kg
CESSNA 337	2100 kg	1270 kg	694 kg	136 kg
TC 690	4683 kg	3054 kg	915 kg	714 kg
GA8 AIRVAN	1814 kg	1229 kg	270 kg	315 kg

Table 11.19: Comparison between the MTOW components for each aircraft used in analysis.

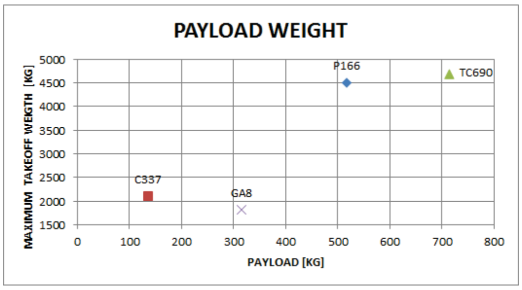


Figure 11.7: Payload weight comparison related to MTOW.

We can note two groups of aircraft, in relation to their MTOW and to the amount of payload that they can carry. It is symptomatic to see a low MTOW group, composed of the GA8 and the C337, two light aircraft but with a difference relative to the number of engines, the first one being a single engine aircraft while the second one a twin engine.

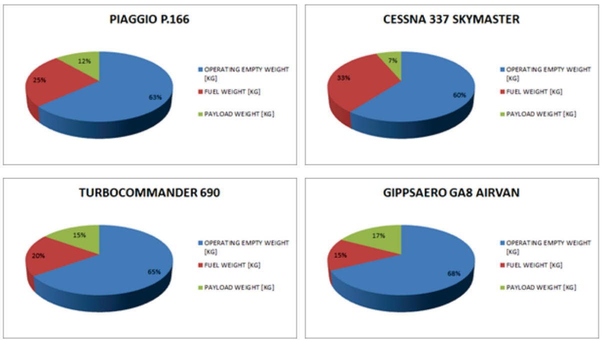


Figure 11.8: Percentage amount of single weight component in MTOW.

Payload percentages are comparable in the last three cases, but for the complexity of the machine segment, the selection is to be made between the Turbocommander 690 and the Piaggio P.166. They are comparable in terms of characteristics. The following tables refer to the internal dimensions of the cabin and all usable volume. Comparing all the aircraft we can see that approximately the same amount of space is available in all the models.

MODEL	LENGTH	HEIGHT	WIDTH
PIAGGIO P.166	3.85 m	1.76 m	1.57m
CESSNA 337	3.02 m	1.30 m	1.12 m
TC 690	4.34 m	1.36 m	1.22 m
GA8 AIRVAN	4.01 m	1.19 m	1.27 m

Table 11.20: Internal dimensions summary.

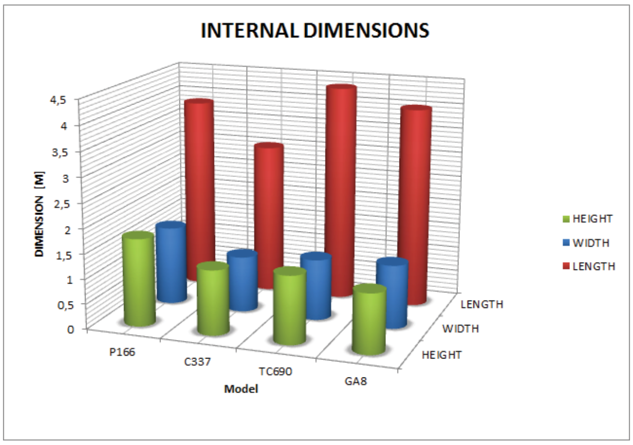


Figure 11.9: Internal dimensions comparison.

Piaggio has well-balanced dimensions with respect to the cabin length, which gives it an advantage in terms of internal cabin volume, making it the best choice compared with the other three aircraft.

MODEL	MTOW	VOLUME
PIAGGIO P.166	4500 kg	10.63 m^3
CESSNA 337	2100 kg	4.39 m^3
TC 690	4683 kg	7.20 m^3
GA8 AIRVAN	1814 kg	6.06 m^3

Table 11.21: Internal cabin volume overview.

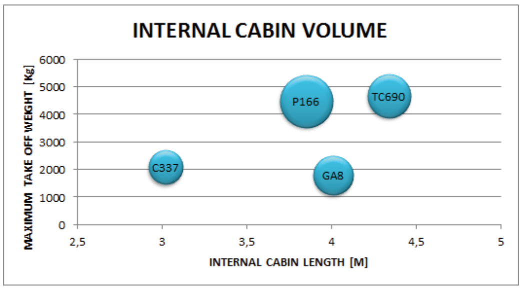


Figure 11.10: Internal cabin volume comparison.

Take off and landing performances For this type of performance analysis, we will refer to a takeoff and landing with an altitude limit of 50 feet, in compliance with the EASA CS 23 normative.

CS 23.53 Take-off performance

(a) *For normal, utility and aerobatic category aeroplanes the take-off distance must be determined in accordance with sub-paragraph*

(b), *using speeds determined in accordance with CS 23.51 (a) and (b). (b) For normal, utility and aerobatic category aeroplanes the distance required to take-off and climb to a height of 15 m (50 ft) above the take-off surface must be determined for each weight, altitude and temperature within the operational limits established for take-off with –*

(1) *Take-off power on each engine*

(2) *Wing flaps in the take-off position(s); and*

(3) *Landing gear extended.[64]*

All the distances are referred to the MTOW airplane configuration.

MODEL	MTOW	T-O (50FT)
PIAGGIO P.166	4500 kg	640 m
CESSNA 337	2100 kg	511 m
TC 690	4683 kg	689 m
GA8 AIRVAN	1814 kg	549 m

Table 11.22: Take-off performances.

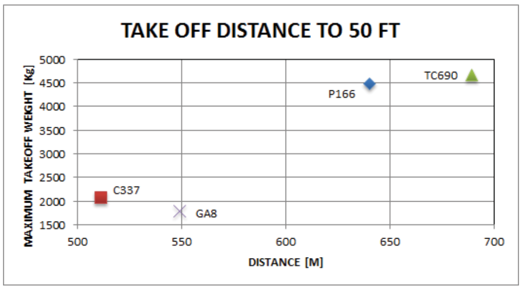


Figure 11.11: Take-off distances comparison.

The same two groups of aircraft demonstrate that weight plays an important role in terms of performance during take-off and landing. We can identify two main groups of aircraft, the light ones and the heavy ones. Our choice, the Piaggio P.166, is more comparable to the Turbo Commander, having the same weight and a similar design. We can also draw the same comparison with regards to landing performance. This data are referred to as the maximum landing weight configuration, described in the EASA CS-23 normative.

CS 23.75 Landing distance

The horizontal distance necessary to land and come to a complete stop from a point 15 m (50 ft) above the landing surface must be determined, for standard temperatures at each weight and altitude within the operational limits established for landing, as follows:

(a) *A steady approach at not less than VREF, determined in accordance with CS 23.73 (a), (b) or (c) as appropriate, must be maintained down to 15 m (50 ft) height and -*

(1) The steady approach must be at a gradient of descent not greater than 5-2% (3°), down to the 15 m (50 ft) height.

(2) In addition, an applicant may demonstrate by tests that a maximum steady approach gradient, steeper than 5-2% (3°), down to the 15 m (50 ft) height is safe. The gradient must be established as an operating limitation and the information necessary to display the gradient must be available to the pilot by an appropriate instrument.

(b) *A constant configuration must be maintained throughout the manouevre;*

(c) *The landing must be made without excessive vertical acceleration or tendency to bounce, nose-over, ground loop, porpoise or water loop.*

(d) *It must be shown that a safe transition to the balked landing conditions of CS 23.77 can be made from the conditions that exist at the 15 m (50 ft) height, at maximum landing weight or the maximum landing weight for altitude and temperature of CS 23.63 (c) (2) or (d) (2), as appropriate.*

(e) *The brakes must not be used so as to cause excessive wear of brakes or tyres.*

(f) *Retardation means other than wheel brakes may be used if that means –*

(1) *Is safe and reliable;*

(2) *Is used so that consistent results can be expected in service; and*

(g) *If any device is used that depends on the operation of any engine, and the landing distance would be increased when a landing is made with that engine inoperative, the landing distance must be determined with that engine inoperative unless the use of other compensating means will result in a landing distance not more than that with each engine operating.[64]*

All the data are referred to landing from a 15 m (50 ft) height with propeller reversal where applicable.

MODEL	MTOW	LANDING (50FT)
PIAGGIO P.166	4500 kg	487 m
CESSNA 337	2100 kg	503 m
TC 690	4683 kg	492 m
GA8 AIRVAN	1814 kg	366 m

Table 11.23: Landing performances.

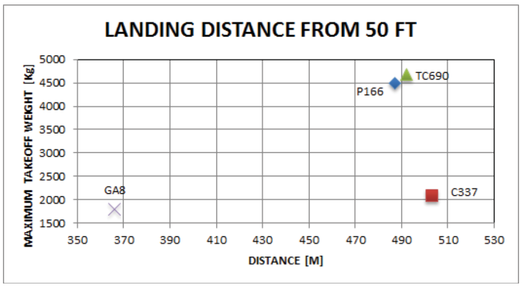


Figure 11.12: Landing distances comparison.

Also in this case, the comparable machines are also the more complex ones. The Piaggio P.166 performance is slightly better than the Turbo Commander, and this gives the Italian aircraft a slight advantage in take-off and landing performance.

Speed and endurance The last requirements to take into account in our analysis are strictly linked to the mission that we would carry out with the spotter aircraft. The aircraft's speed and endurance are closely connected, in order to obtain an endurance value we need in fact to set a particular speed and flight attitude. The mission profile of a spotter aircraft is composed of the transfer from the base to the operation area, the time spent working in the theatre of operations and the return to the airfield where the aircraft is based. Alternatively, in case of firefighting patrol mode, the aircraft takes off from its base, follows a search pattern and returns. The best performance indicator of these two missions is endurance, based on the maximum flight time that the airplane can manage in the mission. All the speed data are referred to the maximum endurance configuration, used for each airplane analyzed in the discussion for the patrol mission they are designed for.

MODEL	MTOW	SPEED
PIAGGIO P.166	4500 kg	162 kts
CESSNA 337	2100 kg	169 kts
TC 690	4683 kg	250 kts
GA8 AIRVAN	1814 kg	104 kts

Table 11.24: Normal operation speed.

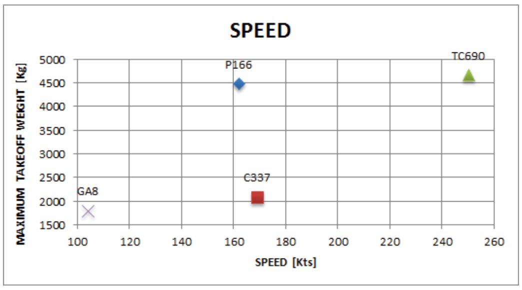


Figure 11.13: Speed comparison.

Endurance is almost the same for the four planes used in the comparison, so this performance indicator is not crucial in the choice of a platform.

MODEL	MTOW	ENDURANCE
PIAGGIO P.166	4500 kg	6 h
CESSNA 337	2100 kg	6 h
TC 690	4683 kg	6 h 48'
GA8 AIRVAN	1814 kg	6 h

Table 11.25: Maximum endurance.

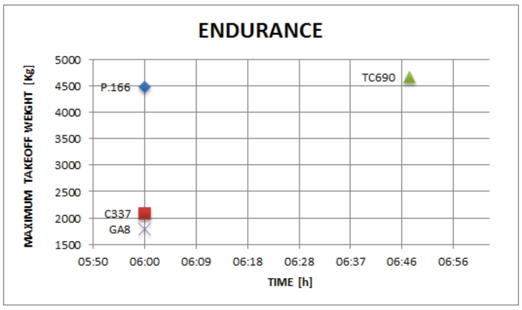


Figure 11.14: Maximum endurance comparison between aircraft.

11.1.2.2 Conclusions

In order to choose the best aircraft for the Remote Sensing suite and for the new firefighting role in the Italian wildfire fighting scenario, the availability of the aircraft has a considerable impact on the decision. The Piaggio P.166 is in line with other aircraft used for the same missions in other countries and is the best choice in some areas of performance.

11.1.3 Piaggio P.166 overview

Figure 11.15: Piaggio P.166 DP1 of Italian Coast Guard.

The Piaggio P.166 is available in various versions. In order to use the only two versions which are in service in the Italian Armed Forces, we will present only the P.166-DL3 and the P-166-DP1.

P.166-DL3 This turboprop version flew for the first time on 3 July 1976, and received FAA and RAI certification in 1978. It can be configured and equipped for a wide variety of duties, including executive transport (EXC); transport and dropping of up to ten paratroops (PAR); air ambulance for two stretchers and two medical attendants (AMB); multi-engine aircrew training (MTR); light tactical transport (LTT); armed military counter-insurgency, field support and search and rescue (AML); maritime reconnaissance (MAR); environmental control and geophysical survey (ECS); aerophotogrammetry (APH); and aerial firefighting (AFF).[73]

TYPE: Twin-turboprop light transport.[74]

WINGS: Shoulder gull-wing cantilever monoplane. NACA 230 wing section. Dihedral 21° 30' on inner portion, 2° 30' on outer wings. Incidence 2°

43' at root. Sweepback 7°30' at quarter-chord. Aluminium alloy flush riveted torsion box structure, with single main spar and auxiliary rear soar. All-metal hydraulically actuated slotted flaps. Rubber boot leading-edge de-icing optional.[74]

FUSELAGE: Aluminium alloy flush riveted semi-monocoque structure of frames and I section extruded stringers: no longerons.[74]

TAIL UNIT: Cantilever aluminium alloy structure, with flush riveted smooth skin on fixed surfaces and beaded skin on control surfaces. Rudder on elevators statically and dynamically balanced. Geared and trim tabs in elevators; trim tab in rudder. Rubber boot leading-edge de-icing of fin and tailplane optional.[74]

LANDING GEAR: Retractable tricycle type. Magnaghi oleopneumatic shock absorbers in all units. Hydraulic actuation. Nosewheel retracts rearward, main units upward. Goodyear 24 x 7.7 mainwheels with size 8.50-10 tyres, pressure 3.79 bars (55lbs/sq in). Goodyear steerable and self-ventring nosewheel with size 6.00/6 tyre, pressure 2.90 bars (42 lb/sq in). Goodyear or Magnaghi hydraulic brakes.[74]

POWER PLANT: Two Avco Lycoming LTP 101-600 turboprop engines, each developing 446.5 kW (599 shp) at take-off, and each driving a Hartzell HC-B3TN-3DL/LT10282-9.5 three-blade constant-speed fully-feathering metal pusher propeller. Available optionally with 503 kW (675 shp) LTP101-700A1A engines. Fuel in two 212 litre (56 US gallon; 46.5 Imp gallon) outer-wing main tanks and two 323 litre (71 Imp gallon) wingtip tanks; total internal fuel capacity 1.070 litres (235 Imp gallons). Gravity refueling points in each main tank and tip tank. Provision for two 177 or 284 litre (39 or 62.5 Imp gallons) underwing drop tanks. Air intakes and propeller blades de-iced by engine exhaust.[73]

ACCOMODATION: Crew of two on raised flight deck, with dual controls. Aft of flight deck is via passenger/cargo double door on port side, forward of wing, or via individual crew door on each side of flight deck to bulkhead at wing main spar; fitting of passenger carrying, cargo or other interiors is facilitated by two continuous rails on cabin floor, permitting considerable flexibility in standard or customized interior layouts. Standard seating for eight passengers, with individual lighting, ventilation and oxygen controls. Flight deck can be separated from passenger cabin by a screen. Door in bulkhead at rear of cabin provides access to utility compartment, in which can be fitted a toilet, bar, or mission equipment for various roles. Entire accommodation is heated, ventilated and soundproofed. Emergency exit forward of wing on starboard side. Windscreen hot-air demisting standard. Windscreen wipers. Washers and methanol spray de-icing optional.[74]

AVIONICS AND EQUIPMENT: Standard avionic packages available to individual customer's requirements; minimum recommended package includes two VHF com, two VHF nav (VOR/ILS), ADF, ATC transponder, compass system and intercom. Optional avionics include radar, autopilot, navigation system and synthesiser type HF radio. Quickly interchangeable individual seats of various types, bench seat, divan stretchers for EXC, PAR, AMB, MTR and LTT versions; strengthened floor in LTT. Four underwing pylons standard on AML, for ordnance, supply containers and auxiliary fuel tanks. Four pylons and integrated search/detection/identification/plotting and reporting system on MAR. Magnetometer, multiscanner and multiple-head camera and associated equipment in ECS version. Two cameras, associated equipment, and ventral sliding doors in APH, with option for four underwing pylons. Internal removable water/extinguisher container and rapid charge/discharge system for AFF.[74]

P.166-DL3MAR Medium-range maritime surveillance version. Applications include coastguard, anti-smuggling, maritime traffic, fishery and pollution control, and search and rescue. Equipped with integrated search/detection/identification/plotting and reporting system, plus four underwing pylons for external weapons or other stores. Capable of operating from unprepared strips, day or night, in all weathers.[73]

AVIONICS AND EQUIPMENT: According to customer and mission requirements. Typical packages may include180° scan search radar, two Vintel aerial cameras. Doppler or other suitable navigation system and operator's console: or 360° search radar, low flight level TV camera with monitor and recorder. Doppler/Omega navigation system and tactical coordinator's console.[73]

P.166-DL3SEM Most recent production reconnaissance version able to carry chin-mounted radar and underwing FLIR sensor; training, transport, medical and special patrol/observation versions offered.[75]

POWER PLANT: Two Textron Lycoming LTP 101-700 turboprops, each flat rated at 447.5 kW (600 shp) and driving a Hartzell HC-B3DL/LT10282-9.5 three-blade constant-speed fully-feathering metal pusher propeller. Fuel in two 212 litre (56 US gallon; 46.5 Imp gallon) outer-wing main tanks, two 323 litre (85.3 US gallon; 71 Imp gallon) fuselage collector tank; total standard internal fuel capacity 1.186 litres (313.3 US gallons; 260.9 Imp gallons). Auxiliary fuel system available optionally, comprising a 232 litre (61.3 US gallons; 51 Imp gallon) fuselage tank, transfer pump and controls; with this installed, total usable fuel capacity is increased to 1.418 litres (374.6 US gallons; 312 Imp gallons). Gravity refueling points in each main tank and tip tank. Provision for two 177 or 284 litre (46.8 or 75 US gallons; 39 or 62.5 Imp gallons) underwing drop tanks. Air intakes and propeller blades de-iced by engine exhaust.[74]

AVIONICS AND EQUIPMENT: UHF-AM, VHF-AM, VHF-FM, encrypted HF and HF/SSB com radios; navigation system includes ANI-7000 Loran-C, Sierra AN/ARN-136A Tacan, Collins VOR-31A VOR/ILS, Collins MC-103 radio compass, direction finder, IFF transponder and radar altimeter. Search and surveillance equipment includes FIAR/Bendix RDR 1500 360° radar with dual CRT colour displays; MSP-Daedalus AA2000 infra-red/ultraviolet linescanning system; 2500 A FLIR system; two 70 mm Vinten aerial cameras (one vertical, one side-looking), and a 3 million candlepower ORC Locator II searchlight under the port wing.[74]

P.166-DP1 Updated version with Pratt & Whitney Canada PT6A-21 turboprops, Collins avionics suite and updated mission systems; first flight 11 May 1999.[75]

POWER PLANT: Two Pratt & Whitney Canada PT6A-121 turboprops, each rated at 458.6 kW (615 shp) maximum continuous power and driving a Hartzell HC-B3DL/LT10282-9.5 three-blade constant-speed fully-feathering metal pusher propeller. Fuel in two 238.5 litre (63 US gallon; 52.5 Imp gallon) outer-wing main tanks, two 329 litre (86.8

US gallon; 72.35 Imp gallon) wingtip tanks, and a 185.5 litre (49.0 US gallon; 40.8 Imp gallon) fuselage collector tank; total standard internal fuel capacity 1,320.5 litres (348.6 US gallons; 290.5 Imp gallons). Auxiliary fuel system available optionally, comprising a 124.9 litre (33.0 US gallons; 27.5 Imp gallon) fuselage tank, transfer pump and controls; with this installed, total usable fuel capacity is increased to 1,445.4 litres (381.6 US gallons; 318 Imp gallons). Gravity refueling points in each main tank and tip tank. Single-point pressure refueling and fuel jettisoning system, permitting partial discharge, optionl. Air intakes and propeller blades de-iced by engine exhaust.[75]

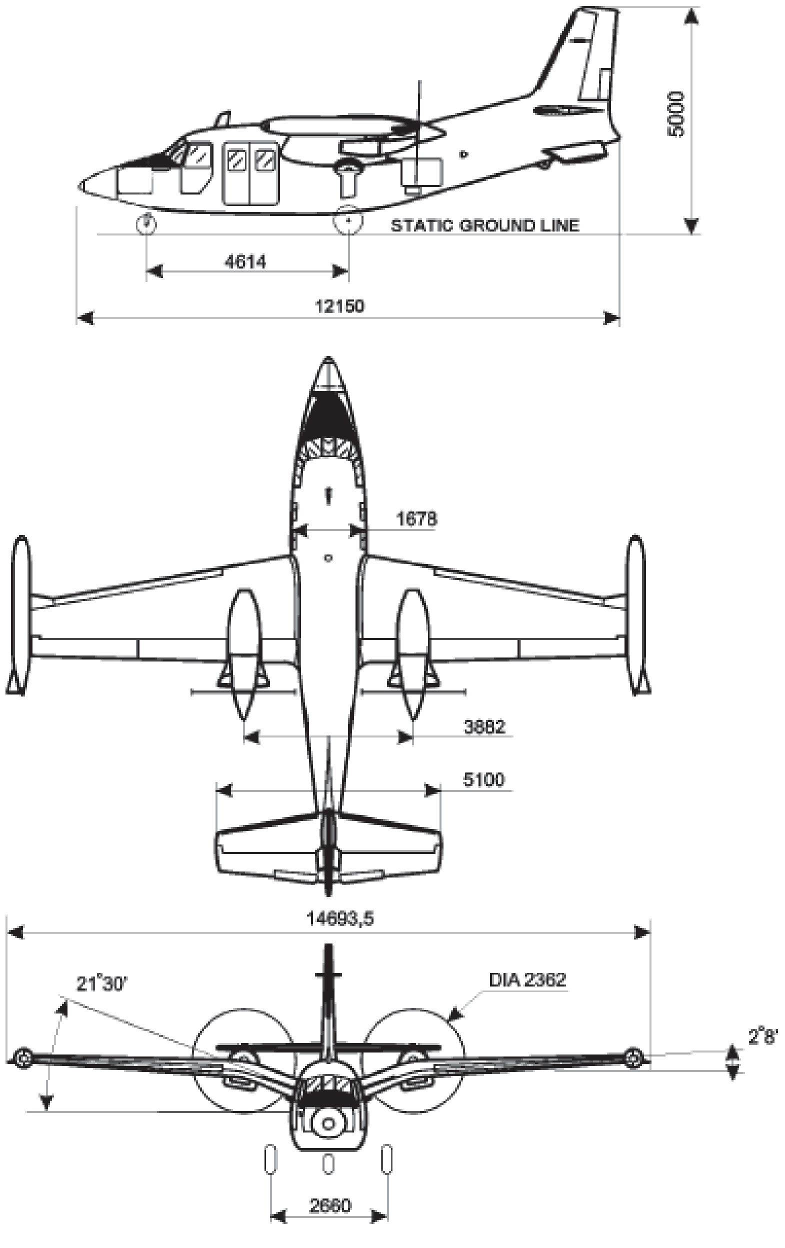


Figure 11.16: Three view Piaggio P.166.

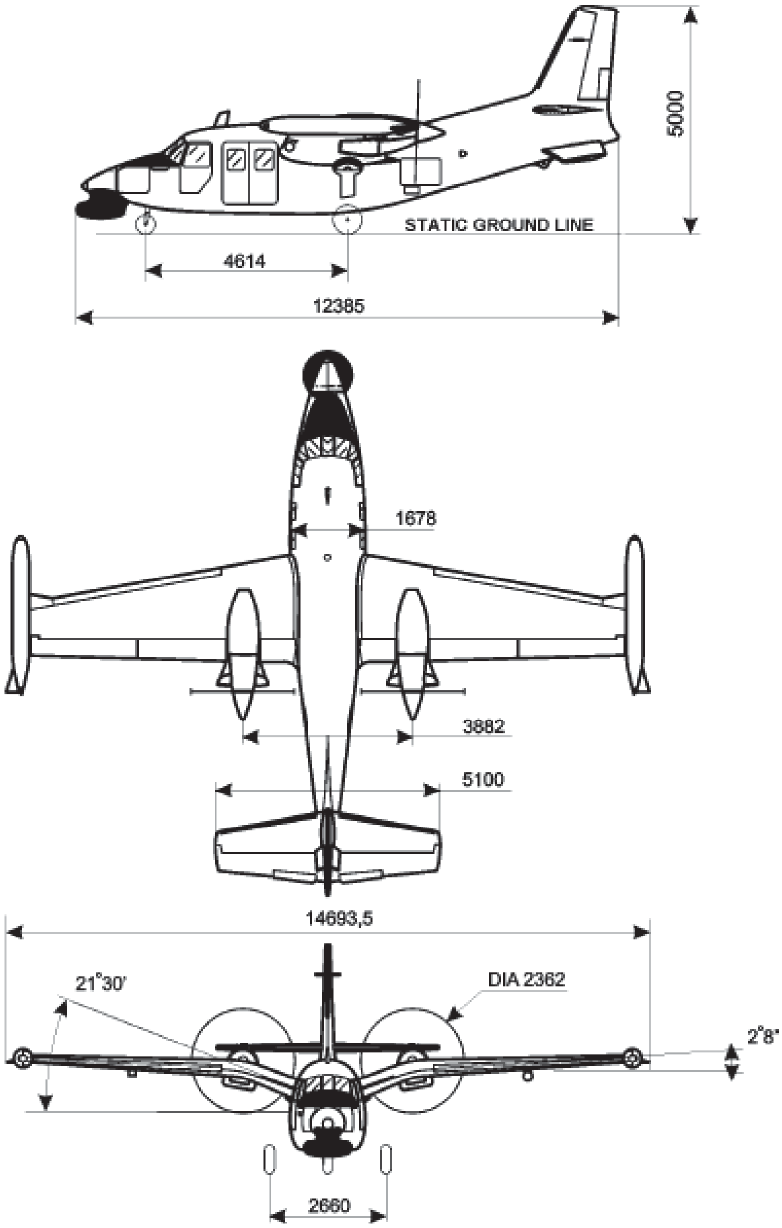


Figure 11.17: Three view Piaggip P.166 with nose radome version.

11.2 P.166 integration with remote sensing suite

When the selection is made, the next step is the integration of the remote sensing suite. P.166 is a platform fitted for the new Aerial Firefighting mission and for other roles in a multi-purpose aircraft. Some device are still present on the operative versions and there are:

- Tactical Consolle;
- FLIR turret; and
- Synthetic Aperture Radar.

This gives us an advantage in terms of integration and reconfiguration work, the only devices to integrate are:

- LiDAR system; and
- Aerial Photography system.

The Aerial Photography system was integrated in a previous version (APH layout) but with four different cameras, one vertical and three perspectival cameras.[77] However we still need to integrate the Remote Sensing suite in order to enable this aircraft to carry out wildfire fighting missions. The first step in the integration process is to evaluate the LiDAR and the Photogrammetry system weights, the second step is the accommodation of the systems, and the last step is the possible update of the existing sensors and a new cabin layout for the firefighting mission.

11.2.1 Sensor integration

In order to make a correct evaluation, weight and dimensions have been taken from datasheets of various products on the market in order to make a statistical analysis. The average data found are used for an assessment of a typical sensor system for a feasibility study. The weigh and volume of the sensor are the two characteristics which need to be taken into account in order to evaluate the physical integration and installation of the sensor on the airborne platform. It will be the future aircraft operator to decide which sensors to install.

11.2.1.1 LiDAR integration

Some systems have been chosen in order to have a wide selection of products available on the market. The weight of the total system is composed of the rack and the sensor, the first is the control unit of the system while the second one is the device being controlled. For our purposes, we will only consider the weight of the sensor, because we have supposed the rack to be included in the Tactical Console hardware. Not all systems are interfaced with a rack, so we have preferred to omit this part in the discussion. The following table shows the weight specifications of the systems taken into consideration.

	Airborne hydrography AB		Leica	Optech		RIEGL		Toposys		MEAN	
MODEL	Dragon eye	Hawk eye II	ALS60	Gemini	Orion	LMS-Q560	LMS-Q680	Falcon II	Harrier 56/G4	Trimmed	Arithmetic
SENSOR WEIGHT	25 kg	95 kg	38.5 kg	23.4 kg	27 kg	16 kg	17.5 kg	41 kg	42 kg	30.63 kg	36.16 kg
RACK WEIGHT	N/A	65 kg	45 kg	53.2 kg	N/A	N/A	N/A	54 kg	42 kg	27.74 kg	28.80 kg
TOTAL	25 kg	160 kg	83.5 kg	76.6 kg	27 kg	16 kg	17.5 kg	95 kg	84 kg	58.37 kg	64.96 kg

Table 11.26: LiDAR airborne sensors used in comparison.[79]

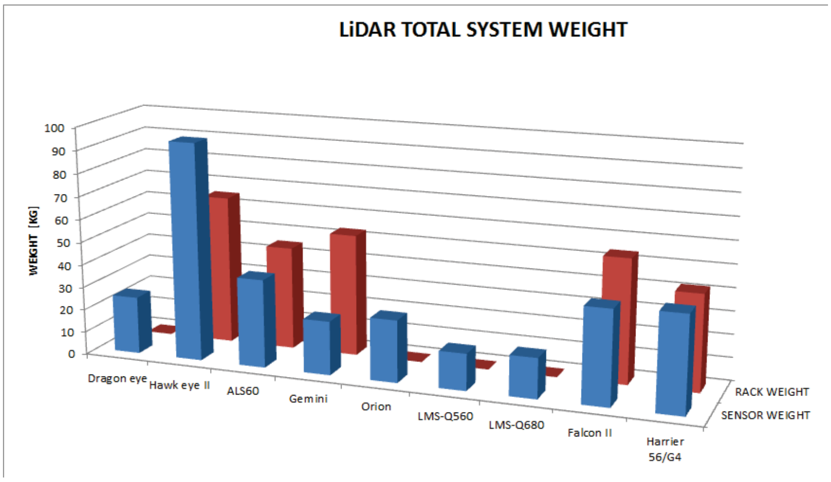


Figure 11.18: LiDAR comparison.

Two types of average have been taken into consideration, the arithmetic one and the trimmed one, considering only the central part of the data, balanced at 30% of the data set.

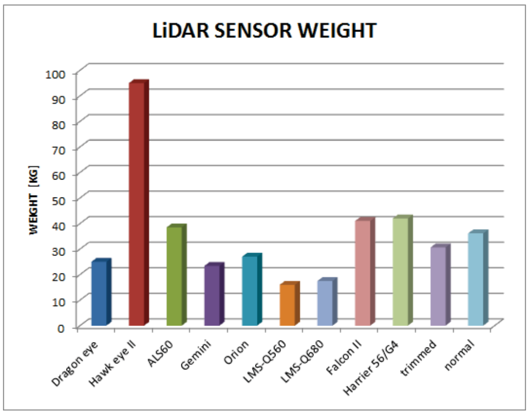


Figure 11.19: LiDAR sensor weight comparison.

In order to have a conservative analysis, we have considered the arithmetic mean, where the sensor weight is calculated at around 35 kg and is controlled by the command console hardware. The volume occupied by the sensor is reported in the following table.

	Airborne hydrography AB		Leica	Optech		RIEGL		Toposys		MEAN	
MODEL	Dragon eye	Hawk eye II	ALS60	Gemini	Orion	LMS-Q560	LMS-Q680	Falcon II	Harrier 56/G4	Trimmed	Arithmetic
LENGHT	0.45 m	1.21 m	0.6 m	0.26 m	0.34 m	0.42 m	0.48 m	0.39 m	0.64 m	0.47 m	0.53 m
WIDTH	0.45 m	0.5 m	0.37 m	0.19 m	0.34 m	0.22 m	0.22 m	0.48 m	0.3 m	0.34 m	0.34 m
HEIGHT	0.25 m	0.62 m	0.27 m	0.57 m	0.26 m	0.23 m	0.23 m	0.45 m	0.48 m	0.36 m	0.37 m
TOTAL	0.05 m^3	0.38 m^3	0.06 m^3	0.03 m^3	0.03 m^3	0.02 m^3	0.02 m^3	0.08 m^3	0.09 m^3	0.05 m^3	0.08 m^3

Table 11.27: LiDAR sensor volume comparison.[79]

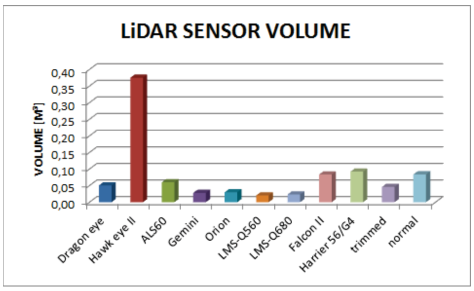


Figure 11.20: LiDAR sensor volume comparison.

11.2.1.2 Aerial camera integration

A list of products available on the market is shown. We have two aerial camera families: the large one and the medium one. In the following tables we have reported all the component weights, namely: sensor, control rack, lens and optional component. The specifications are taken from the datasheets of the products used for the sample survey.

	VISIONMAP	LEICA		IGI	PHASEONE	OPTECH					VEXCEL-MICROSOFT	
	A3	ADS80	RCD30	DIGICAM	iXA	CS-10000	CS-LW640	CS-MS1920	CS-MW640	D-8900	ULTRACAMd	ULTRACAM-X
TYPE	LARGE	LARGE	MEDIUM	MEDIUM	MEDIUM	LARGE	MEDIUM	MEDIUM	MEDIUM	MEDIUM	LARGE	LARGE
SENSOR	38 kg	52 kg	3 kg	1.7 kg	1.7 kg	6 kg	2 kg	2.8 kg	2 kg	4.5 kg	45 kg	55 kg
RACK	N/A	32 kg	5 kg	1.9 kg	N/A	15.5 kg	N/A	9.3 kg	N/A	15 kg	65 kg	65 kg
LENS	N/A	N/A	N/A	1 kg	1.6 kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OPTION	N/A	2.5 kg	0.5 kg	0.9 kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	16 kg
TOTAL	38 kg	150 kg	8.5 kg	5.5 kg	3.3 kg	21.5 kg	2 kg	12.1 kg	2 kg	19.5 kg	110 kg	136 kg

Table 11.28: Aerial cameras component weights.

The weights are evaluated for different camera sizes.

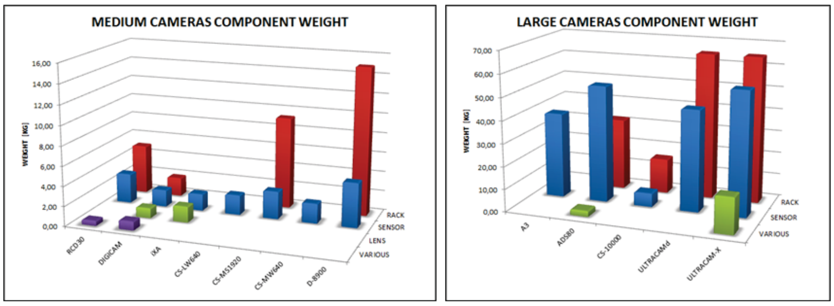


Figure 11.21: Component weights comparison for aerial cameras.

	MEAN VALUES	
	MEDIUM CAMERAS	LARGE CAMERAS
SENSOR	39.2 kg	2.53 kg
RACK	44.38 kg	7.8 kg
LENS	N/A	1.3 kg
VARIOUS	9.25 kg	0.7 kg
TOTAL	91.1 kg	7.55 kg

Table 11.29: Mean values for aerial cameras in realtion to size.

The means are arithmetic, because the data set is made up of homogeneous data. In order to have a conservative analysis, and presuming the control unit is embedded in the tactical console hardware, only the sensor weights have been considered.

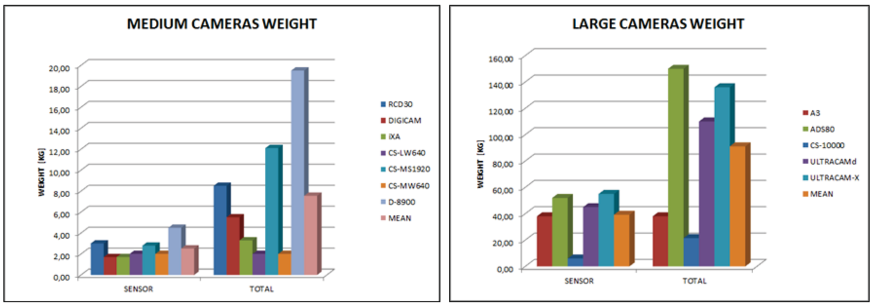


Figure 11.22: Sensor weight for aerial cameras comparison.

In this case, for aerial cameras the means of the sensor weights are:

- For large cameras 39.2 kg;
- For medium cameras 2.53 kg.

We consider the control unit of the two sensors to be already installed, as the control unit is embedded in the hardware of the console used by the TACO. Like the LiDAR sensor, the aerial cameras are evaluated by the volume and the space occupied in the aircraft cabin.

	VISIONMAP	LEICA		IGI	PHASEONE	OPTECH					VEXCEL-MICROSOFT	
	A3	ADS80	RCD30	DIGICAM	iXA	CS-10000	CS-LW640	CS-MS1920	CS-MW640	D-8900	ULTRACAMd	ULTRACAM-X
LENGHT	0.6 m	N/A	N/A	0.1 m	0.13 m	0.13 m	0.12 m	0.15 m	0.12 m	0.2 m	0.45 m	0.45 m
WIDTH	0.6 m	N/A	N/A	0.13 m	0.13 m	0.18 m	0.12 m	0.09 m	0.12 m	0.15 m	0.45 m	0.45 m
HEIGHT	0.5 m	0.7 m	0.22 m	0.11 m	0.11 m	0.25 m	0.16 m	0.1 m	0.16 m	0.12 m	0.6 m	0.6 m
DIAMETER	N/A	0.39 m	0.13 m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
VOLUME	0.18 m^3	0.08 m^3	0.003 m^3	0.002 m^3	0.002 m^3	0.006 m^3	0.0023 m^3	0.0013 m^3	0.0023 m^3	0.0036 m^3	0.12 m^3	0.12 m^3

Table 11.30: Aerial cameras volumes.

The volume is calculated only considering the sensor and, where available, the maximum amount of space occupied by the camera with lenses. The mean of the values produces these results.

	MEAN VALUES	
	MEDIUM CAMERAS	**LARGE CAMERAS**
SENSOR	0.14 m	0.4 m
RACK	0.12 m	0.42 m
LENS	0.14 m	0.53 m
VARIOUS	0.13 m	0.39 m
TOTAL	0.0023 m^3	0.1 m^3

Table 11.31: Volume mean values for aerial cameras.

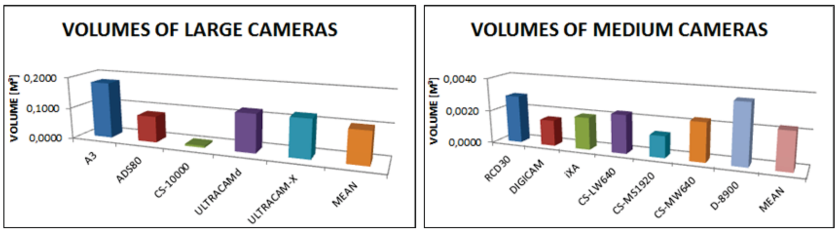


Figure 11.23: Aerial cameras volume comparison.

The evaluation of the sensor to be integrated should be based on a weight and balance analysis and on an analysis of their volumes checked against the available volume of the utility compartment.

11.2.1.3 COA display

Here, we have found a solution by the company Flight Display Systems, which involves two screens one above the other, mounted on the structure via an adjustable arm. The name of the product is FD101DDARM-ML. The specifications are reported in the following table.

SPECIFICATIONS	
DISPLAY TYPE	10.1" TFT color LCD-Dual
DIMENSIONS (INCLUDING THE ARM)	0.368 m (W) x 0.394 m (H) x 0.065 m (D)
LCD DIMENSION	9.80"(W) x 12.10"(H)
WEIGHT	2,.27 kg

Table 11.32: COA display specifications.[100]

Figure 11.24: FD101DDARM-ML display.

11.2.2 Integration analysis

In this section, the following factors will be evaluated:

- Aircraft ergonomics for firefighting role;
- Installation zone;
- Weight and Balance of the new aircraft.

All the discussion in this section is based on the Piaggio P.166's Pilot Operating Handbook data. First of all, the areas influenced by the proposed modifications are identified.

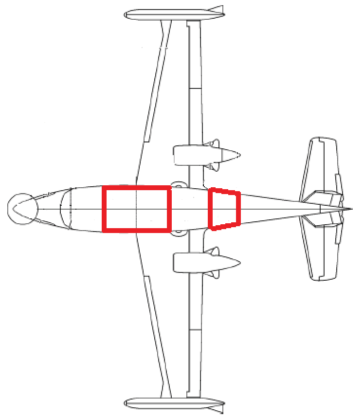


Figure 11.25: Zone of intervention.

There are two areas affected to the modifications:

- Aircraft Cabin;
- Baggage compartment.

The term “cabin” is used to refer to all the space within the fuselage apart from the cockpit. It also includes the area within the fuselage where the sensors are installed and where the members of the tactical crew are seated. As a basis we can use the Piaggio P.166 DP1 with the VMA configuration for Maritime Patrol. This configuration involves a minimum of three people, namely two flight crew, and one console operator, and a maximum of two observers. It is still mounted on the workstation, and handled by the tactical operator. The next step is to identify the best installation area for the sensors and the tactical crew layout, in order to facilitate the operations and achieve a smaller workload. We will compare the available volume within the cabin, and at the same time we will make an estimate of the weight and balance.

11.2.2.1 Spotter aircraft layout

According to the POH[1], the usual layout of Piaggio P.166 DP1 is composed by:

- Cockpit station;

[1] Pilot operative handbook.

- First row station;
- Second row station;
- Toilet station;
- Baggage compartment.

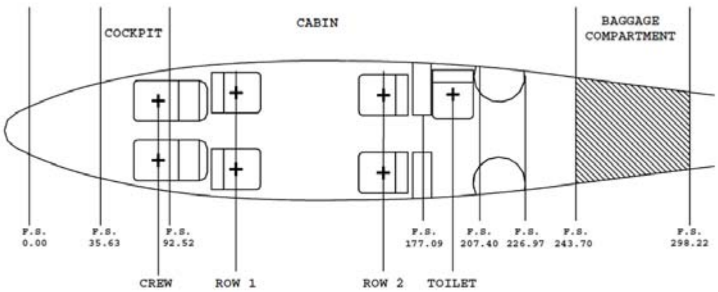


Figure 11.26: Piaggio P.166 interior configuration layout.

Fuselage stations[2] (F.S.) refer to the distance from any component installed on the aircraft and the reference point, which is usually considered to be the first structural part of the fuselage starting from the aircraft radome. The reference point is used as origin of arms used in the weight and balance analysis. The radome is not included in the reference start, because it is not a structural part of the airplane. The usable volume for the reconfiguration to spotter aircraft is composed of cabin and baggage compartment. In this airplane portion, we can install the tactical workstation, the two sensors and the seats for TACO and COA. We can base our dissertation on the VMA configuration with the presence of an existing workstation, a FLIR turret under the left wing and a radar housed in the bulge under the airplane's radome.

[2]Fuselage stations.

Figure 11.27: Nose radome detail.

The cabin will have the layout shown in the picture below.

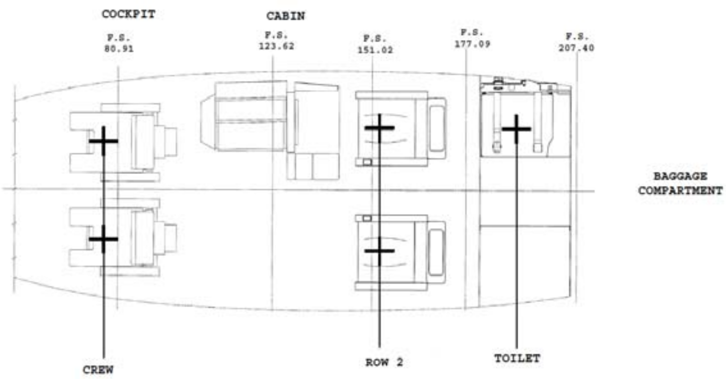


Figure 11.28: Cabin layout in SEM configuration.

The cabin and the cockpit zones have two different entrances. We have kept the cockpit unaltered, and we have worked on a better arrangement of the COA seat in the cabin. The COA is the component of the tactical crew that needs a clear ground view, and consequently his seat must be moved to the first row. In addition to this seat change, installing a bubble window is also suggested, in order to achieve better results in terms of visibility.

Figure 11.29: Bubble window detail.

The cabin door is composed of two windows, and the bubble must be installed on the first windows from the reference point. This and the new workspace allow the COA to have a better view of the ground situation and to have more situational awareness.

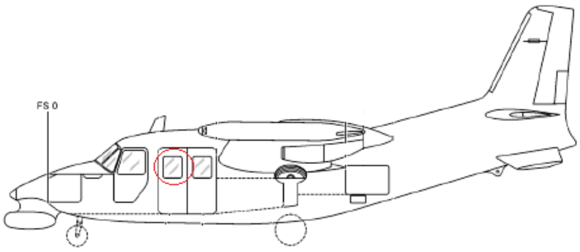


Figure 11.30: Bubble window installation zone.

In the new layout, the COA's seat faces backwards and the TACO sits in front of him. This allows the tactical crew to work face to face with each other and to have a bigger workspace.

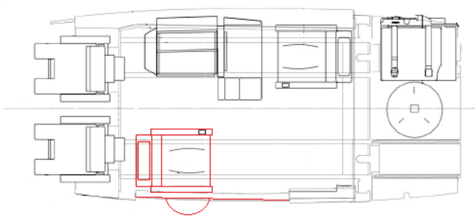


Figure 11.31: COA workspace zone.

11.2.2.2 Sensor installation

The next step focuses on the installation zone of the other two sensors used in firefighting activity. The areas that could house the sensors are:

- Remaining space in the cabin (to the side of the TACO seat);
- Utility compartment;
- Baggage compartment.

According to the POH, baggage compartments have a weight limit of 180 kg, and no easy way of access.

BAGGAGE COMPARTMENT	
WIDTH ACCESS	0.91 m
HEIGHT ACCESS	0.54 m

Table 11.33: Baggage compartment door dimensions.

This means a limited workspace for installation and maintenance of the remote sensor used in this configuration. It is advisable to not use the remaining space in the cabin, in order to facilitate the tactical crew's movements. The only usable space would be the utility compartment, located behind the cabin, occupied by the toilet. The steps for the installation would be:

- Removal of the toilet assembly;
- Integration of LiDAR; and
- Integration of aerial cameras.

The available space in the utility compartment according to the POH is reported in the following table.

UTILITY COMPARTMENT	
LENGTH	0.65 m
WIDTH	1.52 m
HEIGHT	1.70 m
VOLUME	1.68 m^3

Table 11.34: Utility compartment dimensions.

Using the data in the previous chapter for the sensor integration using mean dimensions, we are able to match the information and determine an approximate installation.

	UTILITY COMPARTMENT	LiDAR SENSOR	MEDIUM CAMERA	LARGE CAMERA
LENGTH	0.65 m	0.53 m	0.14 m	0.40 m
WIDTH	1.52 m	0.34 m	0.12 m	0.42 m
HEIGHT	1.70 m	0.37 m	0.14 m	0.53 m
VOLUME	1.68 m^3	0.08 m^3	0.0023 m^3	0.1 m^3

Table 11.35: Utility compartment and sensors dimensions comparison.

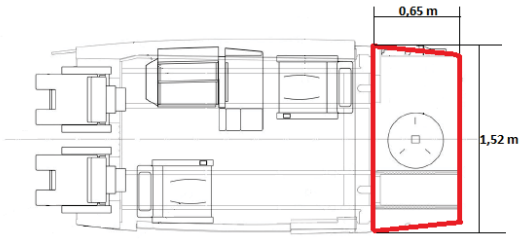


Figure 11.32: Utility compartment dimension.

With the aid of the previous table, we can see that the sensor perfectly fits the utility compartment. We only need to check the weight of the sensor against the relative payload that the P.166 can carry.

11.2.2.3 Weight and balance

This step is the most important, i.e. checking the weight compatibility of the sensor and the reconfiguration of the aircraft, using the payload of the current version of the Piaggio P.166 DP1 in the VMA configuration as a reference parameter. According to the POH, we can use the following weight specifications:

MAXIMUM RAMP WEIGHT	4520 kg	9944 lbs
MAXIMUM TAKE OFF WEIGHT	4500 kg	9900 lbs
MAXIMUM WEIGHT NO FUEL	3715 kg	8173 lbs
EMPTY WEIGHT, EQUIPPED	3130 kg	6886 lbs
MASIMUM USEFUL LOAD (WITH RAMP FUEL)	1390 kg	3058 lbs

Table 11.36: Piaggio P.166 DP1 weights.

From these weights we can deduce the following:

RAMP FUEL WEIGHT	20 kg	44 lbs
FUEL WEIGHT	785 kg	1727 lbs
MAXIMUM PAYLOAD WEIGHT	605 kg	1331 lbs

Table 11.37: Extracted weights.

The first step in evaluating the new Empty Weight Equipped is to make an addition and subtraction operation. We will start from the Empty Weight Equipped for the P.166 in the VMA configuration, it is considered with unusable fuel, operative liquids and lubricants. The added items are:

- Backward-facing seat assembly for the COA;
- LiDAR sensor in utility compartment;
- A large and a medium aerial camera installed in the utility compartment;
- A display assembly for the COA installed on the TACO workstation.

The weight and arm of the backward-facing seat assembly follow the specifications found in the POH. As we do not know specifically which sensor models to install (this will be decided by the aircraft operator), we will refer to a list of LiDAR devices and cameras available on the market. Their characteristics will be used in order to obtain average values, which we will use as reference for our installation. As for the aerial cameras, we have chosen to install two types of cameras, thus increasing operational capability. The display assembly is placed in correspondence to the F.S. of the cabin's first row, as shown in the figure. The items which need to be removed are:

- Observer seat, installed in the second row in the cabin;

- Toilet assembly, installed in the utility compartment.

All the weights and arms are reported in the following table. For a better comprehension of the discussion, the weights are reported in pounds and the arms in inches, in accordance with the POH.

ITEMS ADDED			
ITEM	**WEIGHT**	**ARM**	**MOMENT**
BACKWARD SEAT ASSY	31.5 lbs	110 in	3465 lbs*in
LiDAR	79.552 lbs	191.1 in	15202.4 lbs*in
LARGE CAMERA	86.24 lbs	191.1 in	16480.5 lbs*in
MEDIUM CAMERA	5.566 lbs	191.1 in	1063.6 lbs*in
DISPLAY ASSY	5 lbs	110 in	550 lbs*in
TOTAL	207.8 lbs	176.8 in	36761.5 lbs*in

Table 11.38: Weight and balance components of new item installed.

ITEMS REMOVED			
ITEM	**WEIGHT**	**ARM**	**MOMENT**
TOILET ASSY	29.5 lbs	162.2 in	4784,.9 lbs*in
OBSERVER SEAT ASSY	43.55 lbs	191.1 in	8322.4 lbs*in
TOTAL	73.05 lbs	179.43 in	13107.3 lbs*in

Table 11.39: Eright and balance components of item disembarked.

The new Empty Weight Equipped is found with this formula:

$$W_{OEnew} = W_{OE} + ITEM_{ADD} - ITEM_{REM}$$

EMPTY WEIGHT EQUIPPED	6886 lbs
ITEMS ADDED	+207.8 lbs
ITEMS REMOVED	-73.05 lbs
NEW EMPTY WEIGHT EQUIPPED	7020.8 lbs
NEW MAXIMUM PAYLOAD	1196.2 lbs

Table 11.40: New empty weight equipped and new maximum payload after modification.

The forward and backward limits of the center of gravity with the new empty weight are the same as before, according to excursions of the C.G. reported in the POH. The forward limit is 180.08 inches and the rear limit is 194.00 inches. Now it is possible to find the center of gravity of the new aircraft, using the formula reported in the POH in the chapter dedicated to Weight & Balance of the machine. We have considered the aircraft to be weighed with the platform weighing system, so the formula is:

$$x_{cg} = 212,99 - \left(181,61 \frac{W_{nose}}{W_{OEnew}}\right)$$

The nosewheel weight is about 10% of the total of the Empty Weight Equipped of the airplane.

NEW EMPTY WEIGHT EQUIPPED	7020.8 lbs
NOSEWHEEL WEIGHT	702 lbs
CENTER OF GRAVITY POSITION	194.8 in

Table 11.41: New center of gravity position with the modification.

The C.G. position is slightly towards the back, if considered without crew, fuel and payload. With this information we can make load plans and evaluate whether or not the typical missions are feasible. We have to remember that we cannot have the maximum fuel in the tanks and the maximum payload on board at the same time. In order to carry out the load plan simulations, we must define flight and tactical crew values, every member of the crew will be considered to weigh 85 kg or 187 lbs, in order to have a common standard.

CREW	WEIGHT	ARM	MOMENT	DISPOSITION
COMMANDER	187 lbs	75 in	14025 lbs*in	COCKPIT
FIRST OFFICER	187 lbs	75 in	14025 lbs*in	COCKPIT
COA	187 lbs	118.3 in	22122.1 lbs*in	ROW 1
TACO	187 lbs	154 in	28798 lbs*in	ROW 2
TOTAL	748 lbs	105.575 in	78970.1 lbs*in	

Table 11.42: Crew disposition in new configuration.

Fuel indices are indicated in the POH, and they depend on fuel density. The aircraft uses these types of fuel: JP-8, JP-4, Jet A and Jet A-1. The density ranges from 6.42 lbs/gal (0.77 kg/L) to 6.76 lbs/gal (0.81 kg/L). We will use an intermediate value of 6.59 lbs/gal (0.79 kg/L).

TANK	US GALLONS	LITRES	WEIGHT	MOMENT
COLLECTOR	59 USG	224 lt	390 lbs	84500 lbs*in
WING	168 USG	633 lt	1103 lbs	233800 lbs*in
TIP	341 USG	1288 lt	2243 lbs	464200 lbs*in
AUXILIARY	32 USG	120 lt	211 lbs	60900 lbs*in

Table 11.43: Fuel tanks weight and moment components.

11.2.2.4 Four crew load and fuel near to MTOW

		WEIGHT	ARM	MOMENT
CREW	EMPTY WEIGHT EQUIPPED	7020 lbs	194.8 in	1367857 lbs*in
	FLIGHT CREW	374 lbs	75 in	28050 lbs*in
	COA	187 lbs	118.3 in	22122.1 lbs*in
	TACO	187 lbs	154 in	28798 lbs*in
PARTIAL NO FUEL		7768.8 lbs	186.23 in	1446827 lbs*in
FUEL	COLLECTOR	390 lbs		84500 lbs*in
	PARTIAL 1	8158.8 lbs	187.7 in	1531327 lbs*in
	WING	1103 lbs		233800 lbs*in
	PARTIAL 2	8871.8 lbs	189.4 in	1680627 lbs*in
	TIP	2108 lbs		436900 lbs*in
	PARTIAL 3	9876.8 lbs	190.7 in	1883727 lbs*in

Figure 11.33: Weight and Balance in a typical firefighting mission.

Below is the relative loadsheet.

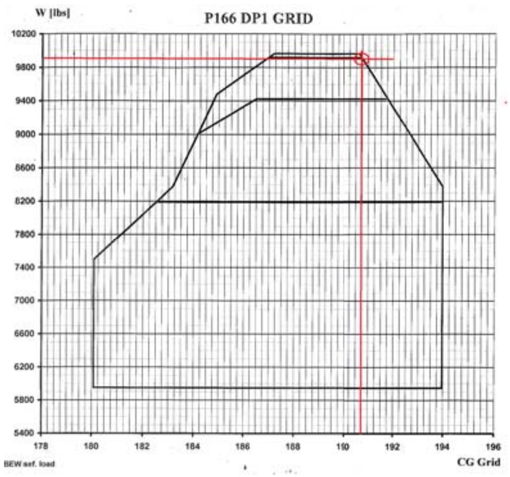


Figure 11.34: Loadsheet for firefighting mission.

11.2.2.5 Three crew load and fuel near to MTOW

		WEIGHT	ARM	MOMENT
CREW	EMPTY WEIGHT EQUIPPED	7020 lbs	194.8 in	1367857 lbs*in
	FLIGHT CREW	374 lbs	75 in	28050 lbs*in
	TACO	187 lbs	154 in	28798 lbs*in
PARTIAL NO FUEL		7581.8 lbs	187.9 in	1424705 lbs*in
FUEL	COLLECTOR	390 lbs		84500 lbs*in
	PARTIAL 1	7971.8 lbs	189.3 in	1509205 lbs*in
	WING	1103 lbs		233800 lbs*in
	PARTIAL 2	8684.8 lbs	190.9 in	1658505 lbs*in
	TIP	2243 lbs		464200 lbs*in
	PARTIAL 3	9824.8 lbs	192.3 in	1888905 lbs*in

Figure 11.35: Weight and Balance in survey mission.

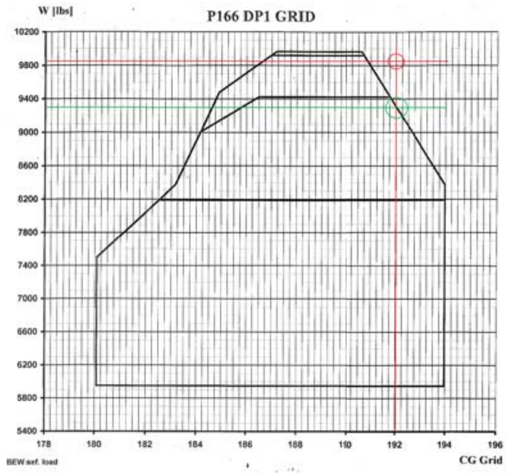


Figure 11.36: Loadsheet for a survey mission.

In this case it is impossible to reach the MTOW, as we are outside the loadsheet, therefore the maximum weight of the aircraft must be 9380 lbs. The justification is found in the POH, which says that the aircraft's CG is at the rear, and because we have installed the sensor in the utility compartment it will follow that the CG will be shifted backwards.

Chapter 12

SYSTEM IMPLEMENTATION

Having selected the remote sensing suite and the platform to use for the new role proposed in the Italian wildfire fighting scenario, we need to make a few considerations about:

- Cost of the system;
- Number of airplanes to refurbish;
- Other possible mission to accomplish;
- Future developments.

12.1 Cost of the system

It is rather difficult to make a cost assessment in our case, because the aircraft used in our work is an existing one, which has been reconverted for a new role, whereas many cost analysis methods are made for new aircraft. There are three ways to establish the cost of an aeronautical system. The first one is based on the cost of the existing platform and on real data about the materials and hours necessary to refurbish the aircraft; the second one is based on costing methods proposed in the aeronautical bibliography, and the last one is based on a proportional evaluation from similar aircraft on a weight-based scale.

12.1.1 Real cost data

This method is the most realistic one but data are so difficult to find because they are covered by industrial secret and the aircraft price is not available for military secret requirements.

12.1.2 Analytical methods

There are two analytical methods proposed:

- "DAPCA IV" from *Raymer's Aircraft Design book*;
- Roskam method, presented in the *Airplane Design*.

Both methods require some information that we cannot know, because they are covered by military secret. In addition to this, the indices proposed in the methods are obsolete and not so applicable to the current aeronautical industry. Another factor that weighs on this decision is that the project we have described in the thesis is not about a new aircraft, but about reconverting an existing one. Therefore the best way to evaluate the cost is to have real cost data, but in order to have an approximate estimate the following method is the best choice.

12.1.3 Proportional evaluation

For the evaluation of the single unit price, we will consider aircraft used in similar missions and then scale the values in relation to the Maximum Empty Weight. For the assessment, we have taken into consideration aircraft used for maritime patrols, which are the most similar aircraft to our spotter aircraft with regards to equipment and requirements.

MODEL	UNIT PRICE	OPERATING EMPTY WEIGHT	PRICE/WEIGHT
ATR42MP	4,500,000 $	11250 kg	4044.444 $/kg
BOMBARDIER DASH-8 MP	55,000,000 $	10024 kg	5486.832 $/kg
SAAB 340 MPA	20,000,000 $	8140 kg	2457.002 $/kg
ATR72MP	86,850,000 $	14586 kg	5954.34 $/kg
CASA C295 MPA	28,000,000 $	11000 kg	2545.455 $/kg

Table 12.1: Unit prices of similar equipped aircraft.

In this scaling operation, it is fundamental to consider the relationship between weight and cost. The price per kilogram factor, put in relation with the Operating Empty Weight, allowed us to find a trend line, in order to have a gross evaluation of the reconverted machine cost. We have used three types of trend line:

- Linear: $y = 0,4526x - 880,75$;
- Second order polynomial: $y = 2e^{-5}x^2 + 0,069x + 1246,1$; and
- Power: $y = 0,0286x^{1,2712}$.

This operations gave us the following results, considering the new Operating Empty Weight of 3,191 kg for the P.166 firefighting spotter version:

TREND LINE TYPE	PRICE/WEIGHT	UNIT PRICE
LINEAR	563.5 $	1,798,117.651 $
POLYNOMIAL	1669.9 $	5,328,742.226 $
POWER	813.9 $	2,597,075.593 $

Table 12.2: Cost esteem.

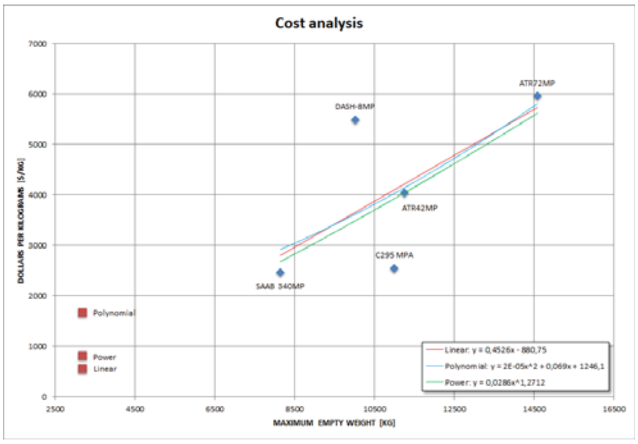


Figure 12.1: Cost esteem diagram.

12.2 Operative scenario

12.2.1 Cost saving

If the airplane was new, and not an aircraft already present in the Italian armed forces fleet, the problem would be to find the minimum number of airplanes to build in order to find the break-even point. The break-even point is defined as the point where there is a balance between loss and profit of a project, the break-even output is the quantity of product to produce in order to break even.

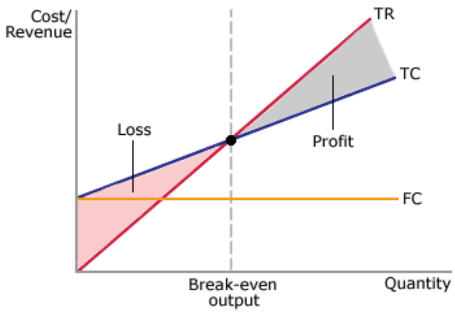


Figure 12.2: Break even point diagram.

The red line represents the total revenue, whereas the blue line represents the total cost of the project. In our case, where the quantity is fixed by the planes' availability in the Italian Armed Forces fleet, the decision to reconfigure aircraft is determined by the advantages in terms of improvements to the plane's operational effectiveness, and to the savings that can be made in terms of flying hours. The cost of suppressing a forest fire generally increases as the size of the fire increases. The importance of this fact, and the fact that losses usually increase with increases in fire size has been known since the early twenties. In general, most forest management strategies pertaining to forest fire protection are designed to reduce the length of time a fire burns Hence, over the years forest protection strategies have been developed that enable managers to detect, action, and extinguishing fires quicker.[78]

SIZE CLASS	N° OF FIRES	AVERAGE AREA BURNED	COST
A (<0,1 ha)	536	51.7 ha	1,014,209 $
B (0,1 ha – 4,0 ha)	368	367.2 ha	2,561,567 $
C (4,1 ha – 40,0 ha)	57	831.7 ha	2,262,820 $
D (40,1 ha – 200,0 ha)	19	879.4 ha	3,338,310 $
E (>200,0 ha)	7	9241.4 ha	6,143,472 $
Sum of all classes	987	11371.4 ha	15,320,378 $

Table 12.3: Cost of wildfires in relation to size.[78]

These human infrared scanners enable fire suppression personnel to collect fire intelligence information not currently available visually. As a result, the general consensus is that better decisions are made relative to fire control strategies and tactics, and that these decisions significantly reduce suppression costs and losses to values-at-risk.[78] The percentage of economic and area saved with the use of FLIR are reported in the following table. Only skimmer type water bombers, the only fixed wing aerial resource used for wildfire fighting operations, have been considered.

	OPTION A	OPTION B	OPTION C
FLYING COST SAVED	15,9%	7,8%	9,6%
RETARDANT COST SAVED	16,6%	6,4%	10,7%
AREA SAVED	13,2%	5,2%	9,5%

Table 12.4: Cost saving percentage.[78]

The other remote sensors installed make the pre- and post-fire assessments quicker and cheaper, as it enables the crew to fly over sensible areas during the same mission and to collect the data needed for the data-acquiring operation.

12.2.2 Number of aircraft to refurbish

After analyzing the costs, the next question is the number of airplanes to refurbish. In the previous chapter, we have discussed the hypothesis that a break-even point doesn't exist in our case, because our aircraft would only change its configuration and would not be mass-produced. The only reason to set a minimum number of airplanes to reconfigure is linked to the operational tasks to be carried out. The operative reasons in Italy would be:

- Fire seasons;
- Bases used for water bombers;
- Best territorial coverage.

In the first part of this thesis, we have seen that fire risk in Italy is highest in two main seasons: summer and winter. The only region that has a high fire risk all year round is Liguria. In winter the risk is higher in the northern regions of Italy, where wildfires have more chance to ignite in the Alps. In the summer, wildfire risk is higher in the southern part of the country and in the two major Italian islands, Sardinia and Sicily. The number of bases varies from a maximum of six to a minimum of three during the winter season.

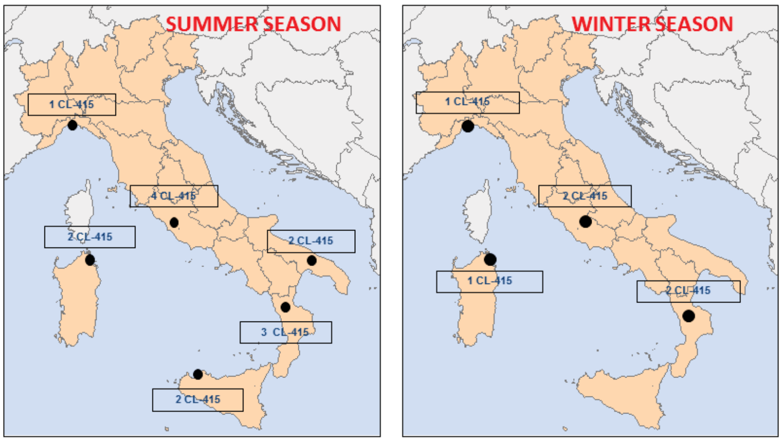


Figure 12.3: Italian water bomber deployement.

The best choice is to have one P.166 DP1/AIB for each base, in order to cover the territory during the summer and to have a homogenous distribution of aerial resources in all the Italian peninsula. One or two aircraft could be reconverted just for backup and for any additional demand in severe fires. During the winter, having one P.166 DP1/AIB in each base would cover all the territory, engaging the other resources for other missions that we will describe in the following section.

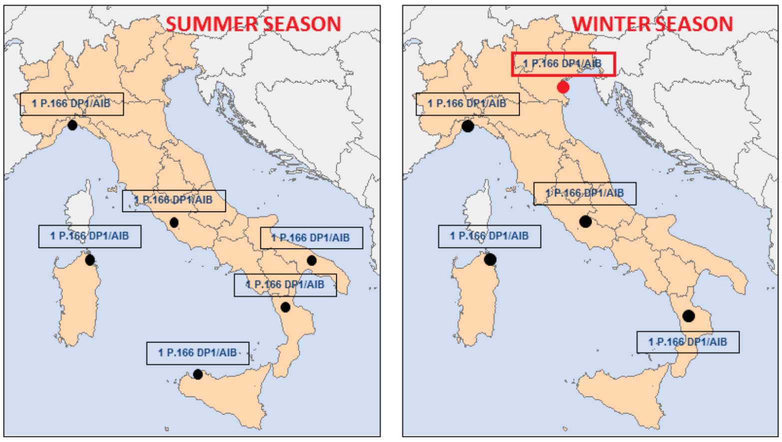


Figure 12.4: Piaggio P.166 DP1/AIB deployement envision.

Adding one more base during the winter would be the best allocation of resources. Venice could be one possible choice in order to cover the entire Alpine area. Knowing the high fire risk of Liguria, another base would be beneficial to the readiness and the quickness of the wildfire fighting organization. A base in Genoa could cover all the north-eastern part of Italy, while the Venice base the north-western part of the country, thus sharing the duties of fire patrol over the Alps. In conclusion, the best scenario is to have eight Piaggio P.166 DP1/AIB, of which 6 are operative and 2 are used as backups in the Italian wildfire fighting fleet.

12.3 Other missions for P.166 DP1/AIB

The P.166 DP1 equipped for firefighting spotter missions could also be used for other missions, making this aircraft a multi-mission resource. This remote sensing configuration was studied for these purposes:

- Command and control platform for natural and human disasters and emergency situations;
- Environmental surveys and cadastral patrols;
- Light maritime patrol.

12.3.1 Disaster emergency

The refurbished aircraft could be used during natural and human disasters for the command and control of aerial rescue resources and ground teams, which could be flown to the affected areas. The airborne remote sensing suite could have a positive impact on search and rescue missions. It could be fundamental in directing operations thanks to the situational awareness of the tactical crew. SAR operations in natural disasters could deal with:

- People missing during floods;
- People missing during earthquakes;
- Disasters evaluation;
- Oil spills and disasters in offshore platform.

12.3.2 Environmental control and cadastral patrol

One version of this aircraft P.166 DP1/SEM was designed for environmental and pollution monitoring, and the inclusion of new sensors has increased its potential for this type of mission. Cadastral patrolling is another option, both for the control of environmental crimes and for pre-fire assessment, in order to locate any buildings in dangerous positions. Environmental monitoring includes these type of activities:

- Pollution monitoring;
- Avalanche monitoring;
- Forest environment monitoring;
- Coast shore and erosion monitoring; and
- Illegal dumping monitoring.

12.3.3 Light maritime patrol

The last type of optional mission that this reconfigured aircraft could carry out is a medium-short range maritime patrol. The primary role of the Piaggio P.166 DP1 was to patrol the Italian shores for national security and for maritime search and rescue. It would be an excellent backup in case the other aerial resources for maritime patrol are engaged in other patrol operations or physically in other Italian areas.

12.4 Future developments

We can divide future developments in two fields:

- Firefighting spotter aircraft improvements;
- Interaction between spotter aircraft and water bomber improvements.

12.4.1 Spotter aircraft

Many improvements could be made on the choice of remote sensors, such as using more compact and lighter sensors, in order to have a better performance using up less useful payload. Another improvement could be made to the aircraft's balance. The position of the center of gravity in the P.166 is towards the rear. Installing the sensor in the utility compartment emphasizes this characteristic, with flight limitations in flying performances. An engine change is not required, because Pratt & Whitney PT6 installed on the P.166 DP1 are the latest product of this engine family, with a good fuel efficiency and better flight performances. An integration of a better satcom system and data link could be necessary, in order to increase the volume of data that can be sent.

12.4.2 Interaction between spotter aircraft and bombers

This is the most interesting part of the future developments, based on an avionics hardware upgrade of the water bombers used in Italy. Cartographic resources for dropping operations are fundamental for the safety of the mission, so a data link preferential channel of interaction between spotter aircraft and water bombers could be a good improvement. Spotter aircraft send electronically a map of the area with highlighted points that could be dangerous for the mission safety and the dropping procedures. With the same system, the COA could transmit the intelligence about the area of operations in every single mission, and a water bomber could operate at the same time over two wildfires without the necessary information, which would be sent at a later stage by the spotter unit through data link or directly from the ground station of DOS/ROS. The last improvement could be the development of a synthetic vision system that would act as dropping aid for aerial firefighting pilots. This would help them fly through the smoke via head-up displays during the operations. The dropping path would be elaborated and validated by the tactical crew and used as advice for the extinguishing operations.

Figure 12.5: Canadair CL-415 in action.

Chapter 13

CONCLUDING REMARKS

The present thesis focused on a possible improvement of the Italian firefighting system based on a new figure in the operational procedures of firefighting operations, and a new mission to be implemented in the aerial firefighting component. The work was developed into two main sections: mission analysis and spotter aircraft system design.

In the mission analysis part, we found weaknesses in command chain elements during the firefighting operations. In order to reduce workload and consequently increase operation safety in aerial firefighting, a new role must be introduced in the operational structure. The new figure of the COA (Coordinatore Operazioni Antincendio) would be a precious aid for the commander in charge on the fire location. Integration of this role in the command chain means a new filter tier for the operations. The COA would command and control all the aerial resources in the theatre of operations, protecting ground teams from dangerous situations that might take place in case of misunderstandings between the aerial and the ground teams. The COA is in direct contact with the incident commander that leads all the operations, but the aerial resources would not be in direct contact with the DOS and would be managed only by the COA from a convenient and safe airborne position. Another aspect which emerged from mission analysis is the lack of a scientific approach to the Italian wildfire fighting system. In fact, this does not involve briefing or debriefing operations, nor does it make use of remote sensing aids, which could be valuable tools to study the wildfire in post-fire assessments. Debriefing operations would be valuable in order to record any positive or negative situations verified on the field, and consequently be able to have all actors involved in firefighting subject to continuous training in order to increase the level of standards and achieve safer procedures. The last note is about the regional fleets which are all composed by helicopters. This is not advisable, as the best choice for a quick fire attack is fixed-wing aircraft. Therefore, our suggestion is to assemble heterogeneous regional fleets with a balanced mix of fixed- and rotary-wing aircraft.

The lack of a spotter aircraft role has clearly emerged from this study. In order to cover all the phases of wildfire development and to aid the commander in charge, an appropriate remote sensing suite would be integrated on this type of aircraft. In addtion to wildfire spotting and monitoring in their initial stage, this aircraft should be equipped to fulfil an augmented role, consisting in an innovative command and control airborne platform. The second part of the thesis thus focuses on the possibility to acquire an aircraft that fits well within this specialized role. Possible sensors that could be installed aboard for a firefighting mission and consequently for a possible multi-purpose mission have been analyzed. Four sensors have been selected for integration: LiDAR, aerial photography, FLIR turret and a synthetic aperture radar. In addition to firefighting, this remote sensing suite could be used for SAR operations, environmental monitoring and command operations during civil protection missions. We have studied an architecture for the workstation to be installed on the spotter aircraft to achieve the best possible operation capabilities depending on the mission to be accomplished. Adhering to the current aerial firefighting philosophy, we decided to use an existing aircraft and reconvert it for this new mission type. The best aircraft to reconvert, selected according to mission and design criteria and fleet availability in Italy, is the Piaggio P.166 DP1. This airplane will be soon retired from service in the Italian armed forces and consequently there will be a significant surplus of units. The P.166 aircraft is already configured for patrol missions and some remote sensors are already installed, inducing minimal changes to the current configuration. This would naturally contain reconfiguration costs. Weight and balance analysis confirmed that the aircraft loadsheet permits the flight mission in fully safe conditions.

Many future improvements can be made, ranging from mission analysis to the choice of the airplane platform. New real-time data links may be studied for the rapid sharing of wildfire intelligence between the actors working in suppression operations, providing real time fire development, in order to take the right decision at the right time. The spotter aircraft could be the brain of the aerial operations, guiding water bombers along an optimized drop path by means of synthetic vision avionics installed onboard. A systematic patrol path could be introduced, so as to enable the tactical crew aboard the spotter aircraft to call on all the necessary resources, with direct coordination from the COAU center in Rome. For the second part, the improvements concern the type of remote sensing aids, as the technology progresses, we will have more powerful sensors with increased performance, that can be useful for our purposes. Therefore, continuous attention to this remote sensing aspect and workstation is crucial to achieve an efficient resource in such a key role as the spotter aircraft. Due to the age of the aircraft selected in this work, a further study and investigation could be performed, to find other, younger aircraft present in the Italian scenario to be reconfigured to carry out the same types of mission. For patrol purposes, the aircraft could be supported by light UAV in zones with a medium risk of wildfires during the summer season. Notably, the role of the spotter aircraft could not be replaced by this type of aircraft, since the situational awareness of the COA is a precious resource to use in command and control operations.

Clearly, the presented cost analysis could be significantly improved in absence of industrial and military confidentiality upon key information. The total price of the P.166 system and the cost of every single sensor to be integrated is unknown, therefore the analysis, carried out with a proportional method, must be considered only to convey an approximate idea, and involves a wide safety margin.

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