Scholars Journal of Engineering and Technology (SJET)
Abbreviated Key Title: Sch. J. Eng. Tech.
ISSN 2347-9523 (Print)
ISSN 2321-435X (Online)

A Unit of Scholars Academic and Scientific Society, India
www.saspublishers.com

Determining Aircraft Landing Speed Using Standard Methods from Numerical Optimization for Real-Time Control Allocation

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Original Research Article

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Article History
Received: 23.10.2018
Accepted: 01.11.2018
Published: 30.12.2018

DOI:
10.36347/sjet.2018.v06i12.001

Abstract: Intensive studies on Control Allocation (CA) problems have been carried out and various methods presented in a wide range of applications such as control systems, marine vehicles, and biomechanical control. Direct CA was introduced in which the choice of control inputs is made by geometric reasoning. However, rigorous and painstaking computations for calculating geometric relationships are required in the numerical algorithm for this method. Several fast techniques were proposed to obviate this problem. Hence, to solve this bound-constrained problem, optimization-based allocation, which uses linear programming, quadratic programming and other optimization methods, was developed. This paper is concerned with a different approach of computing the solution for this CA objective using optimization-based method.
Keywords: Aircraft landing speed, Standard methods, Numerical optimization, Real-Time, Control allocation.

INTRODUCTION

One of the central techniques in Machine Learning is Numerical Optimization [1]. Widely put, Global optimization is the branch of applied mathematics and numerical analysis that is concerned with the development of deterministic algorithms that are capable of guaranteeing convergence in finite time to the actual optimal solution of a nonconvex problem. For many problems, figuring out the best solutions directly is usually hard. However, the relatively best and easy approach is to set up a loss function that measures how good a solution is. Thereafter, the parameters of that function are minimized to find the sought after best solution.

In our context, a loss function or cost function is a function that maps an event or values of one or more variables onto a real number intuitively representing some "costs" associated with the event.

In mathematics and computer science, an optimization problem is the problem of finding the best solution from the best feasible solutions. Optimization problems can be divided into two categories depending on whether the variables are discrete or continuous. An optimization problem seeks to minimize a loss function. An objective function is either a loss function or its negative which is either called a reward function, a profit function, a utility function or a fitness function, in which case it is to be maximized. When we maximize an objective function, we are essentially carrying out the process of optimization [2].

There are known, many factors that influence aircraft performances such as operator, aerodrome, takeoff weight, available control systems, flight instruments and many others. Aircraft performances are calculated are usually calculated from aircraft characteristics provided by manufacturers with the help of complex formulae. Most of these characteristics are provided in Base of Aircraft Data [3], a model which is a de facto standard for short-term and long-term 4D trajectory calculations. Certain forces that cause aircraft motion are considered. The algorithm presented here is proposed as a means of improving on existing control allocation (CA) standards.

Brief Background

There are three phases during aircraft flight that can be improved upon namely, takeoff, cruise and landing. Of these phases, takeoff and landing are the most strictly controlled or regulated segments or phases of a flight. Due entirely to different reasons, even though takeoff and landing represent only a very small portion of the total flight operation of an aircraft, performance of these two phases is considered very important. Different methods are usually applied to carry this out. The most acceptable system is the flight management system. The flight management system (FMS) is a device used in all new and current aircrafts to assist the pilot with several tasks such as navigation, guidance, trajectory prediction and flight path planning [4]. The aspect of takeoff and landing fall under flight path planning. Prior to departure, every aircraft files in a flight plan. This is because it would not be possible to distinguish aircraft types and other important attributes and data with radar's help only. The flight plan holds other important information for air traffic control such as aircraft type, airline operator, airport of departure, airport of destination, time of departure, expected time of arrival, and many others. All these additional attributes are recorded with every aircraft performance. This enables the machine learning model to distinguish between flights based on many other attributes and not only on aircraft types.

This paper is meant to address the landing phase of an aircraft by proposing an algorithm to calculate the landing speed. The energy share factor defines how much of the available power is allocated to vertical evolution as opposed to acceleration during aircraft climbs and deceleration during descents. Emphasis is laid on descents or landing because most optimization possibilities are feasible during this segment of flight duration. Thus, solution to the optimization algorithm presented in the next section is meant to maximize the general operation in the airport by standardizing the landing speed of aircrafts within the airport for optimized profits. Optimization of profits in itself is the main thrust of a commercialized airport.

Backstepping, as a nonlinear control design method that provides an alternative to feedback linearization, is borne in mind as the recursive iteration goes on. Backstepping is used here to derive robust linear control laws for two nonlinear systems which are related to angle of attack control and flight path angle control, respectively [5]. These translate to carrying out the optimization process in x and y dimensions which are essentially nonlinear, these two phases are most vulnerable to known air accidents and eventual mishaps during flight. According to available data and records, physical and social vulnerability and eventual exposure have increased at all levels of the developmental process to the extent that this has brought or is thought to contribute to the ever persistent, if not increasing, disaster losses experienced over a reasonable period [6, 7]. This is carried out in the next section of this presentation which is the methodology.

METHODOLOGY

Using Standard Method from Numerical Optimization for Real Time Control Allocation (CA) to Determine the Landing Speed of an Aircraft

A backstepping and control allocation with application to flight control using neural network controller has an aircraft that lands in two types of weather A and B (good and bad weather, respectively) that require speeds P1 and P2, also, respectively. Each unit of type A requires 1km/h of P1 and 2km/h of P2. Type B requires 2km/h of P1 and 1km/h of P2 (each unit). The Airport has only 100km/h of P1 and 80km/h of P2. Each unit of type A brings a profit of #500 and each unit of type B brings a profit of #400. Deduce and develop an optimization algorithm to maximize profit that will improve flight control in the airport.

Solution

The formulated situation above is one that is obviously practical in everyday flight operations. It is particularly of interest to the researcher because with the exception of very few military airports, most others are meant to generate and maximize profits hence, the need to optimize operations in them. Given this background, we continue as outlined hereunder.

The pieces of information contained in the formulated problem are transformed in a tabular form as shown in the following table.

Speeds	P1 (km/h)	P2 (km/h)	Profit (#)
A	1	2	500
B	2	1	400
	100	80	

Decision variable: The decision variables are speeds A and B. Thus let the number of speed A be x while that of B is y.
Objective function: The given problem is aimed at maximizing profit.
Let Z be the objective function profit of each unit of type A = #500, that is, profit of x unit of type A = #500x.

Profit of each unit of type B = #400, that is, profit of y unit of type B = #400y.
Total profit = 500x + 400y. --1
Constraints (i): Company has only 100km/h of P1
Unit of A requires 1km/h of P1, that is, x-unit requires x-km/h of P1.
1 unit of B requires 2km/h of P1.
Thus y-unit requires 2y-km/h of P1
Thus total available quantity of P1 for A and B = 100km/h
Therefore x + 2y <= 100---2
Constraint (ii): Company has only 80km/h of P2.
1 Unit of A requires 2km/h of P2.
Thus x- unit requires 2x – km/h
1 Unit of B requires 1km/h of P2.
Thus y – units requires y – km/h.
Total available quantity of P2 for A and B = 80 km/h.
That is 2x + y <= 80 --3

Constraint (iii): Supply of A and B cannot be negative, That is x >= 0 and y >= 0
The mathematical model formulation for improving backstepping and control allocation with application to flight control using neural network controller technique becomes
Maximize Z = 500x + 400y--4
Subject to x + 2y <= 100---5
2x + y <= 80--6
x >= 0 and y >= 0

Then use simplex method to solve the mathematical model of equations 4, 5 and 6
z = 500x + 400y-----------------------------------7
x + 2y <= 100---8
2x + y <= 80---9

Equate equation 7 to zero and remove all the constraints in equations 8 and 9 respectively by introducing slacks
Z – 500x – 400y = 0--------------------------------10
x + 2y + S1 = 100------------------------------------11
2x + y + S2 = 80--------------------------------------12

No of iterations	Basic	Z	X	y	S1	S2	Sol
Iteration 1	Z	1	-500	-400	0	0	0
	S1	0	1	2	1	0	100
S2 leaves x enters	S2	0	2	1	0	1	80
Iteration 2	Z	1	0	-150	0	250	20000
	S1	0	0	3/2	1	-1/2	60
	X	0	1	½	0	½	40
Iteration 3	Z	1	0	0	100	200	26000
	Y	0	0	1	2/3	-1/3	40
	X	0	1	0	-1/3	2/3	20

Total sensor monitoring time, z = 26000 seconds
Speed P1 = 20 km/h
Speed P2 = 40 km/h
Step2: To find the key column go for the most negative in the z row which is -500
Step 3 To find the key row use the positive numbers in the key column to divide their respective solutions whichever gives the smaller answer is where the key row falls 100/1 = 100, 80/2 = 40
Step 4: To fill the pivot row x use the number that is at the point of intersection in the key row and key column of iteration 1 which is 2 to divide all the numbers in S2 row of iteration1.
z = 0/2 = 0, x = 2/2 = 1, y=1/2 = 1/2, S1 = 0/2 = 0, S2 = 1/2= 1/2,
Sol = 80/2 = 40km/h.
Step 5: To fill the 2 row of iteration 2.Recall new No = old NO – (pivot No x Constant) z= 1 – (0 x -500) = 1
x = -500 – (1x-500) = -500+500 =0

y = -400 – (1/2x-500) = -400+250 = -150
s1 = 0 – (0x-500) = 0
s2 = 0 – (1/2 x -500) = 0 + 250 =250
Sol = 0 – (40 x -500) = 20000secs.
Step 6: To fill s1 row of iteration 2.
z = 0 – (0x1) = 0
x = 1 – (1x1) = 0
y = 2- (1/2x1) = 2 -1/2 = 4-1/2 =3/2
s1 = 1 – (0x1) = 1
s2 = 0 – (1/2x1) = -1/2
Sol = 100 – (40x1) = 60km/h
Step 7: To find the key row in iteration 2
60/3/2= 60/1 x2/3 = 40
40/1/2 = 40/1 x 2/1 = 80
Step 8: To fill the pivot row of iteration 3
z = 0/3/2 = 0
x = 0/3/2 = 0
y = 3/2/3/2 =3/2 x 2/3 =1
s1 = 1/3/2 = 1/1 x 2/3 =2/3
Sol = 60/3/2 = 60/1 x 2/3 = 40
Step 9: To fill the 2 row of iteration3
z = 1 – (0 x -150) = 1
x = 0 – (0 x -150) = 0
y = -150 – (1 x -150) = -150+150 = 0
s1 = 0 – (2/3 x – 150) = 0 + 100 = 100
s2 = 250 – (-1/3 x -150) 250 – 50 = 200
Sol = 20000 – (40 x 150)
20000 + 6000 = 26000
Step 10: To fill x row of iteration 3
z = 0 – (0 x 1/2) = 0
x = 1 – (0 x 1/2) = 1
y = 1/2 – (1 x 1/2) = ½ - ½ = 0
s1 = 0 – (2/3 x ½) = - 1/3
s2 = ½ - (-1/3 x ½) = ½ +1/6 =2/8 = 3+1/6 =4/6 =2/3
Sol = 40 – (40 x 1/2) = 40 - 20 = 20km/h

The solution, 20km/h, is that optimal speed at which an aircraft will land in the airport to guarantee and ensure optimized profit.

OBSERVATIONS AND COMMENTS

It is observed that applying our optimization procedure, in this case, modular iteration, the landing speeds regressively changed a most fitting optimized value was obtained. The different iterations were meant to ensure that the best optimized value was achieved. The choice of this optimization technique among a host of others is to avoid the use of rigorous computations of these nonlinear geometric relationships so that the bound-constrained problem could be solved [8]. It should also be noted that instead of using recursive algorithm which will require a repetitive process as is the case when solving rather complicated problems, iterative algorithm is used here thus, arriving at our desired destination faster with assured and reliable result. Should recursion approach have been used, the function calls itself till the desired condition is met. This is usually slower than iteration, hence, our choice for this optimization procedure using the method of iteration in this paper as earlier mentioned.

From the foregoing, graphs of controlled and uncontrolled landing speeds of an aircraft was subsequently generated as shown followed by a comparison of both to buttress the need for the optimization process and the applied control in this paper.

Table-4.1: Simulated landing controlled speed of an aircraft

Landing controlled speed of an aircraft(km/h)	Time (s)
0	0
27	1
18	2
23	3
21	5
21	10

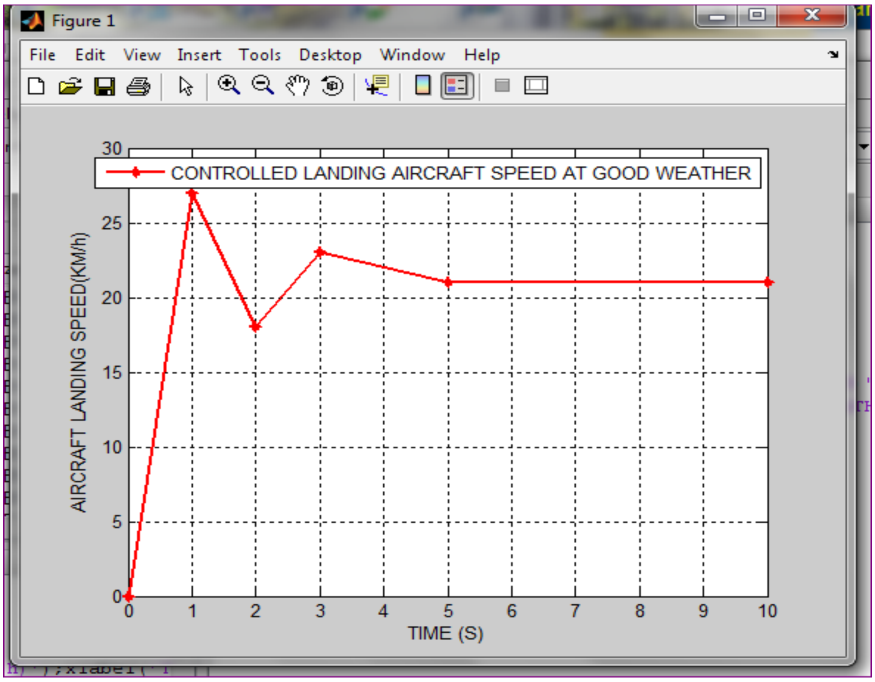

Fig-4.1: Simulated result of controlled landing aircraft speed at good weather

Table-4.2: Simulated landing uncontrolled speed of an aircraft

Landing uncontrolled speed of an aircraft(km/h)	Time (s)
0	0
30	1
61	2
69	3
73	5
73	10

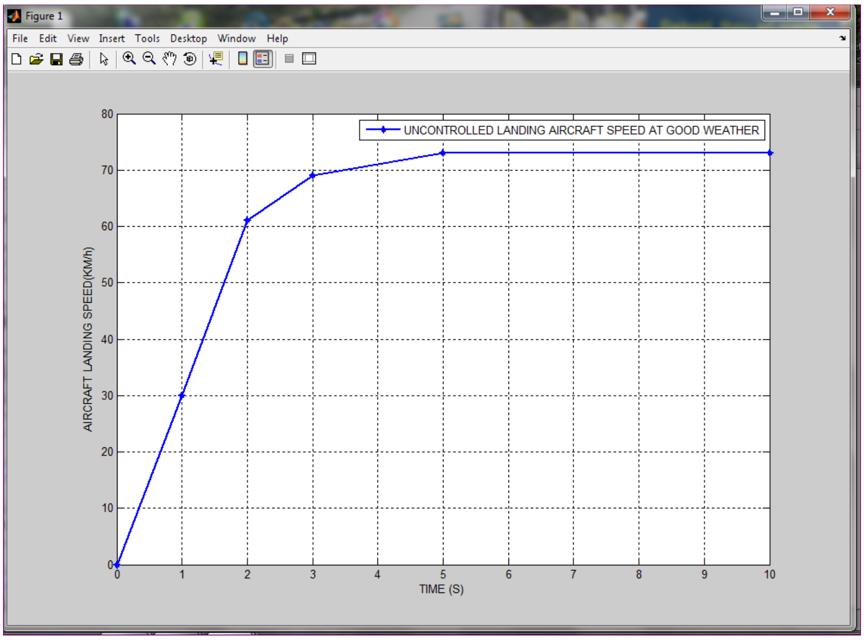

Fig-4.2: Simulated result of uncontrolled landing aircraft speed at good weather

Table-4.3: Comparison of the simulated landing controlled and uncontrolled speed of an aircraft

Controlled landing speed of an aircraft(km/h)	Uncontrolled landing speed of an aircraft(km/h)	Time (s)
0	0	0
27	30	1
18	61	2
23	69	3
21	73	5
21	73	10

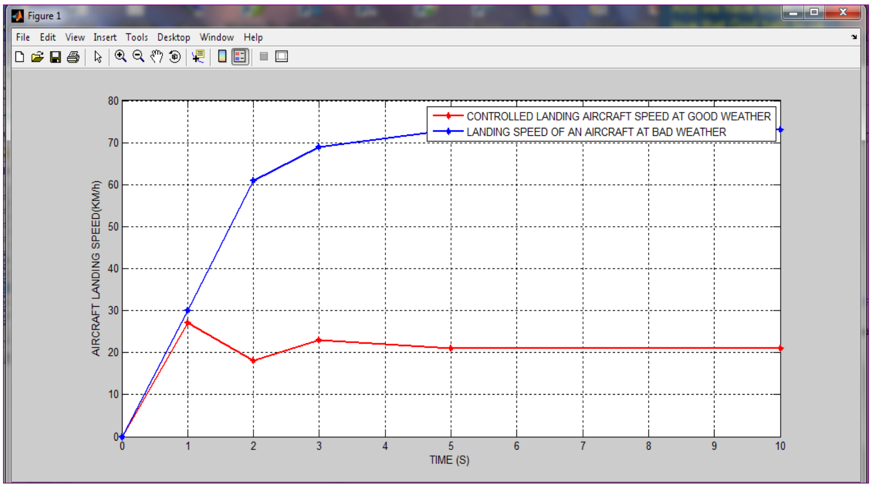

Fig-4.3: Simulated result of controlled and uncontrolled landing aircraft speed at good and bad weather

CONCLUSION

The method presented here is an effort to ensure a somewhat standardized landing speed for an aircraft, considering the nonlinear pattern of the forces acting on it. The procedure takes into account the weather impacts on aircrafts landing such that, in our case, types A and B weather conditions were considered. Thus, generalized or standardized approach to the issue of aircraft landing in the airport could be deduced. This will ensure both efficient aircraft use of the airport as well as an enhanced operation for a maximized profit for the airport managers and commercial operators [9, 10]. This is the ultimate goal of a commercialized airport.

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