Online ISSN : 2249-4596
Print ISSN : 0975-5861

Global Journal of Researches in Engineering: B

Automotive Engineering

Highlights

- Study of Cost Estimation
- Preliminary Aircraft Design
- Heat Release Model
- Design and Weight Estimation

Discovering Thoughts, Inventing Future

VOLUME 14 ISSUE 4 VERSION 1.0

Global Journal of Researches in Engineering: B
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Automotive Engineering
Volume 14 Issue 4 (Ver. 1.0)

Open Association of Research Society

Incorporation No.: 0423089
License No.: 42125/022010/1186
Registration No.: 430374
Import-Export Code: 1109007027
Employer Identification Number (EIN): USA Tax ID: 98-0673427

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United States of America
USA Toll Free: +001-888-839-7392
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Offset Typesetting

Global Journals Incorporated
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Pin: CR9 2ER, United Kingdom

Packaging & Continental Dispatching

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Contents of the Volume

Global Journal of Researches in Engineering: B
Automotive Engineering
Volume 14 Issue 4 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

An Algorithm for Solving Bi-Criteria Large Scale Transshipment Problems

By Khalid Alkhulaifi, Jasem AlRajhi, Elsayed E. M. Ellaimony, Mohsen AlArdhi & Hilal A. Abdelwali
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Abstract- This paper describes an algorithm for solving a certain class of bi-criteria multistage transportation problems with transshipment (BMTSP). A several bi-criteria multistage transportation problem with transshipment are formulated. The presented algorithm is mainly based on application of the methods of solving bi-criteria single stage transportation problems, utilizing available decomposition techniques for solving large-scale linear programming problems, and the methods of treating the transshipment problems. The mathematical formulation of the presented class does not affect the special structure of the transshipment problem for each of the individual stages. An illustrative example is introduced to validate that the implementation of the algorithm.

Keywords: large scale transportation problem, transshipment problem, multi-objective, decision making, decomposition technique of linear programming.

GJRE-B Classification : FOR Code: 090299

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An Algorithm for Solving Bi-Criteria Large Scale Transshipment Problems

Khalid Alkhulaifi [α], Jasem AlRajhi [σ], Elsayed E. M. Ellaimony [ρ], Mohsen AlArdhi [Ѡ] & Hilal A. Abdelwali [¥]

Abstract- This paper describes an algorithm for solving a certain class of bi-criteria multistage transportation problems with transshipment (BMTSP). A several bi-criteria multistage transportation problem with transshipment are formulated. The presented algorithm is mainly based on application of the methods of solving bi-criteria single stage transportation problems, utilizing available decomposition techniques for solving large-scale linear programming problems, and the methods of treating the transshipment problems. The mathematical formulation of the presented class does not affect the special structure of the transshipment problem for each of the individual stages. An illustrative example is introduced to validate that the implementation of the algorithm.

Keywords: large scale transportation problem, transshipment problem, multi-objective, decision making, decomposition technique of linear programming.

I. Introduction

When shipments go directly from a supply point to a demand point, i.e. shipments do not take place between origins or between destinations nor from destinations to origins, it is called a classical transportation problem. In many real life situations, shipments are allowed between supply points or between demand points. There are many points (called transshipment points) through which goods can be transshipped on their journey from a supply point to a demand point. Shipping problems with any or all of these characteristics are considered as transshipment problems. It was first introduced by Orden (1965) [1] in which he introduced an extension of the original transportation problem to include the possibility of transshipment. The problem of determining simultaneously the flow of primary products through processors to the market of final products has been formulated alternatively as a transshipment model by multi-regional, multi-product, and multi-plant problem formulated in the form of general linear programming model has been proposed by Judge et al (1965) [4]. Later, various alternative formulations of the transshipment problem within the framework of the transportation model that permits solution of problems of the type discussed by King and Logan without the need for subtraction of artificial variables were discussed by Hurt and Tramel (1965) [5]. On the other hand, Grag and Prakash (1985) [6] studied time minimizing transshipment problem. Then dynamic transshipment problem was studied by Herer and Tzur (2001) [7]. Ozdemir (2006) studied Multi location transshipment problem with capacitated production and lost sales afterwards [8]. Furthermore, Osman et al (1984) [9] introduced an algorithm for solving bi-criteria multistage transportation problems.

Recently, Khurana et al (2011) [10] studied a transshipment problem with mixed constraints. He introduced an algorithm for solving time minimizing capacitated transshipment problem [11]. Abo-elnaga et al (2012) [12] introduced a trust region globalization strategy to solve multi-objective transportation, assignment, and transshipment problems. Khurana (2013) [13] introduced a Multi-index fixed charge bi-criterion transshipment problem. Rajendran et al [14] (2012) presented A new method namely, splitting method, to solve fully interval transshipment problems. Zaki et al [15] (2012) used the genetic algorithm for solving transportation, assignment, and transshipment problems. Ojha et al [16] (2011) formulated single and multi-objective transportation models with fuzzy relations under the fuzzy logic. Saraj et al [17] (2010) solved the multi objective transportation problem (MOTP) under fuzziness using interval numbers. Abd El-Wahed [18] (2001) presented a multi-objective transportation problem under fuzziness. Das et al [19] (1999) introduced a multi-objective transportation problem with interval cost, source and destination parameters.

In this paper a formulation of different structures of bi-criteria large-scale transshipment problems and an algorithm for solving a class of them, which can be solved using the decomposition technique of linear programming by utilizing the special nature of transshipment problems, is presented. The new algorithm determines the points of the non-dominated set in the objective space. The method consists of solving the same multistage transshipment problem repeatedly but with different objectives and each

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iteration gives either new non-dominated extreme point or changes the direction of search in the objective space. An illustrative example is presented in this paper.

II. Formulation of Bi-criteria Multistage Transshipment Problems

The formulation of different bi-criteria multistage transportation problems with transshipment presented in this paper covers several real situations as shown in the following cases.

a) Bi-Criteria Multistage Transportation Problem with transshipment of the First Kind (BMTSP 1)

This case represents multistage transshipment problems without any restrictions on intermediate stages. In order to develop a mathematical formulation of the problems, it is assumed that the availabilities are "aj", where j= 1, 2, 3, ..n and "n" is the number of sources and destinations. Where as the requirements are "b_j", j= 1, 2, 3, ….., n. The minimum transportation costs and deteriorations from i to j are "c_{ij}","d_{ij}" where i and j= 1, 2, 3, …., n. X_{ij} denotes the quantity shipped from i to j; and "xj_{jj}" is the neat amount transshipped through point j where $x_{ij} \geq 0$. Then the problem takes the form:

$$Min.Z_1 = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}x_{ij}$$

$$Z_2 = \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij}$$

Where $c_{ij} = 0$ for the quantity shipped from the source "Si" to itself and from destination "Dj" to itself:.

$$\sum_{\substack{i=1\\ i\neq j}}^{n} x_{ji} - x_{jj} = a_j,\ j = 1,2,\ldots,n.$$

$$\sum_{\substack{i=1\\ i\neq j}}^{n} x_{ij} - x_{jj} = b_j,\ j = 1,2,\ldots,n.$$

$x_{ij} \geq 0$ for all i, j.

b) Bi-criteria Multistage Transportation Problem withTransshipment of the Second Kind (BMTSP 2):

This case represents bi-criteria multistage transshipment problems in which the transportation at any stage is independent of the transportation of the other stages. In order to obtain the mathematical formulation of the problem which represents this case, it is assumed that for k^{th} stage, k=1,2,3,…N. The availabilities are: $(a_{jk}^k), j_k = 1,2,3,\ldots n_k$, n_k is the number of sources and destinations at the k^{th} stage; the requirements are: $(b_{jk}^k), j_k = 1,2,3,\ldots n_k$ the transportation costs and deteriorations are $c_{i_k j_k}^k$ and $d_{i_k j_k}^k$ where i_k= 1,2, 3, ., nk; jk= 1, 2, 3, ., nk. $x_{i_k j_k}^k$ denotes the quantity shipped from i_k to j_k and $x_{j\,j}^k$ is the net amount transshipped through point j_k, $x_{j_k j_k}^k \geq 0$.

Then the problem takes the form:

$$Min.Z_1^k = \sum_{i_k=1}^{n_k}\sum_{j_k=1}^{n_k} c_{i_k j_k}^k x_{i_k j_k}^k$$

$$Z_2^k = \sum_{i_k=1}^{n_k}\sum_{j_k=1}^{n_k} d_{i_k j_k}^k x_{i_k j_k}^k$$

Where $c_{i_k j_k}^k = 0$ for the quantity shipped from the source (S_i) to itself and from the destination (D_j) to itself as follows:.

$$\sum_{\substack{i_k=1\\ i_k\neq j_k}}^{n_k} x_{j_k i_k}^k - x_{j_k j_k}^k = a_{j_k}^k,\ j_k = 1,2,\ldots,n.$$

$$\sum_{\substack{i_k=1\\ i_k\neq j_k}}^{n_k} x_{i_k j_k}^k - x_{j_k j_k}^k = b_{j_k}^k,\ j_k = 1,2,\ldots,n.$$

$x_{ij} \geq 0$ for all i_k, j_k.

and the minimum transportation cost is given by:

$$MinZ = \sum_{k=1}^{n} MinZ^k$$

c) Bi-Criteria Multistage Transportation Problem With Transshipment of the Third Kind (BMTSP 3):

This case represents bi-criteria multistage transshipment problems with some additional transportation restrictions on the intermediate stages which does not affect the transshipment problem formulation at each stage. The mathematical formulation of the problem representing this case is given as:

$$Min.Z_1 = \sum_{i_1=1}^{n_1}\sum_{j_1=1}^{n_1} c_{i_1 j_1}^1 x_{i_1 j_1}^1 + \ldots + \sum_{i_k=1}^{n_k}\sum_{j_k=1}^{n_k} c_{i_k j_k}^k x_{i_k j_k}^k + \ldots$$

$$\ldots + \sum_{i_N=1}^{n_N}\sum_{j_N=1}^{n_N} c_{i_N j_N}^N x_{i_N j_N}^N$$

$$Z_2 = \sum_{i_1=1}^{n_1}\sum_{j_1=1}^{n_1} d_{i_1 j_1}^1 x_{i_1 j_1}^1 + \ldots + \sum_{i_k=1}^{n_k}\sum_{j_k=1}^{n_k} d_{i_k j_k}^k x_{i_k j_k}^k + \ldots$$

$$\ldots + \sum_{i_N=1}^{n_N}\sum_{j_N=1}^{n_N} d_{i_N j_N}^N x_{i_N j_N}^N$$

Where $c^k_{i_k j_k}$ and $d^k_{i_k j_k} = 0$ for the quantity shipped from the source $S^k_{i_k}$ to itself and from the destination $D^k_{j_k}$ to itself: k = 1, 2,…, N

$$\sum_{\substack{i_1=1\\ i_1\neq j_1}}^{n_1} x^1_{j_1 i_1} - x^1_{j_1 j_1} = a^1_{j_1}, j_1 = 1,2,\dots,n_1$$

$$\sum_{\substack{i_1\neq j_1\\ i_1=1}}^{n_1} x^1_{i_1 j_1} - x^1_{j_1 j_1} = b^1_{j_1}, j_1 = 1,2,\dots,n_1$$

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$$\sum_{\substack{i_k\neq j_k\\ i_k=1}}^{n_k} x^k_{j_k j_k} - x^k_{j_k j_k} = a^k_{j_k}, j_k = 1,2,\dots,n_k$$

$$\sum_{\substack{i_k\neq j_k\\ i_k=1}}^{n_k} x^k_{i_k j_k} - x^k_{j_k j_k} = b^k_{j_k}, j_k = 1,2,\dots,n_k$$

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$$\sum_{\substack{i_N\neq j_N\\ i_N=1}}^{n_N} x^N_{j_N i_N} - x^N_{j_N j_N} = a^N_{j_N}, j_N = 1,2,\dots,n_N$$

$$\sum_{\substack{i_N\neq j_N\\ i_N=1}}^{n_N} x^N_{i_N j_N} - x^N_{j_N j_N} = b^N_{j_N}, j_N = 1,2,\dots,n_N$$

$$F_{r_k}(x^{k-1}_{i_{k-1} j_{k-1}}, x^k_{i_k j_k}, x^{k+1}_{i_{k+1} j_{k+1}}) = 0,$$

$$x^1_{i_1 j_1} \geq 0,.., x^k_{i_k j_k} \geq 0,..x^N_{i_N j_N} \geq 0$$

For all $i_1,\dots,i_K,\dots,i_N; j_1,\dots,j_K,\dots,j_N;$

where: $F_{r_k}, k = 1,2,\dots,N$ are linear functions representing the additional transportation restrictions and r_k is the number of this linear functions at the k^{th} stage.

d) Bi-Criteria Multistage Transportation Problem wth transshipment of the Fourth Kind (BMTSP 4)

This case represents bi-criteria multistage transshipment problems in which the difference between the input and output transportation commodity is known at the sources (destinations) of each intermediate stage. The assumed transportation restrictions in this case affect the transshipment formulation of each individual stage.

The mathematical formulation of the problem representing this case is given as:

$$Min.Z_1 = \sum_{i_1=1}^{n_1}\sum_{j_1=1}^{n_1} c^1_{i_1 j_1} x^1_{i_1 j_1} + \dots + \sum_{i_k=1}^{n_k}\sum_{j_k=1}^{n_k} c^k_{i_k j_k} x^k_{i_k j_k} + \dots$$

$$\dots + \sum_{i_N=1}^{n_N}\sum_{j_N=1}^{n_N} c^N_{i_N j_N} x^N_{i_N j_N}$$

$$Z_2 = \sum_{i_1=1}^{n_1}\sum_{j_1=1}^{n_1} d^1_{i_1 j_1} x^1_{i_1 j_1} + \dots + \sum_{i_k=1}^{n_k}\sum_{j_k=1}^{n_k} d^k_{i_k j_k} x^k_{i_k j_k} + \dots$$

$$\dots + \sum_{i_N=1}^{n_N}\sum_{j_N=1}^{n_N} d^N_{i_N j_N} x^N_{i_N j_N}$$

Where $c^k_{i_k j_k}$ and $d^k_{i_k j_k} = 0$ for the quantity shipped from the source $S^k_{i_k}$ to itself and from the destination $D^k_{j_k}$ to itself: k = 1, 2, …, N

$$\sum_{\substack{i_1\neq j_1\\ i_1=1}}^{n_1} x^1_{j_1 i_1} - x^1_{j_1 j_1} = a^1_{j_1}, j_1 = 1,2,\dots,n_1$$

$$\sum_{\substack{i_1\neq j_1\\ i_1=1}}^{n_1} x^1_{i_1 j_1} - x^1_{j_1 j_1} - (\sum_{\substack{i_2\neq j_2\\ i_2=1}}^{n_2} x^2_{j_2 i_2} - x^2_{j_2 j_2}) = b^1_{j_1}, j_1 = 1,2,\dots,n_1; j_2 = 1,2,\dots n_2$$

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$$\sum_{\substack{i_{k-1}\neq j_{k-1}\\ i_{k-1}=1}}^{n_{k-1}} x^{k-1}_{i_{k-1} j_{k-1}} - x^{k-1}_{j_{k-1} j_{k-1}} - (\sum_{\substack{i_k\neq j_k\\ i_k=1}}^{n_k} x^k_{j_k i_k} - x^k_{j_k j_k}) = b^{k-1}_{j_{k-1}}, j_{k-1} = 1,2,\dots,n_{k-1}; j_k = 1,2,\dots n_k$$

$$\sum_{\substack{i_{N-1}\neq j_{N-1}\\ i_{N-1}=1}}^{n_{N-1}} x^{N-1}_{i_{N-1} j_{N-1}} - x^{N-1}_{j_{N-1} j_{N-1}} - (\sum_{\substack{i_N\neq j_N\\ i_N=1}}^{n_N} x^N_{j_N i_N} - x^N_{j_N j_N}) = b^{N-1}_{j_{N-1}},$$

$$j_{N-1} = 1,2,\dots,n_{N-1}; j_N = 1,2,\dots n_N$$

$$\sum_{\substack{i_N\neq j_N\\ i_N=1}}^{n_N} x^N_{i_N j_N} - x^N_{j_N j_N} = b^N_{j_N}, j_N = 1,2,\dots,n_N$$

$x^k_{i_k j_k} \geq 0$ for all i_k, j_k; k=1, 2, …, N

(BMTSP 1) is solved as a bi-criteria single stage transshipment problem.

(BMTSP 2) can be solved as N single stage bi-criteria transshipment problems and the minimum value of the total transport costs and deteriorations are obtained as the sum of the minimum transportation costs and deteriorations for each individual stage.

(BMTSP 3) can be solved using the decomposition technique utilizing the special nature of transshipment problems. The next section will be devoted to the solution of this type of problems.

(BMTSP 4) is solved using any method for solving bi-criteria linear programming problems.

Global Journal of Researches in Engineering (B) Volume XIV Issue IV Version I Year 2014

e) An Algorithm for Solving BMTSP 3

The decomposition technique of linear programming can be used to solve the bi-criteria multistage transshipment problems especially for the (BMTSP 3) type. This type of bi-criteria multistage transshipment problems decomposed into [2, 3, 5, 8]:

- Sub problems corresponding to every stage.
- A master program which ties together the sub problems.

Let:

D^k be the matrix consisting of the coefficients of k^{th} sub-problem constraints.

A^k the matrix consisting of the coefficients of k^{th} stage tie-in constraints.

b the vector of constant coefficients in the tie-in constraints.

b^k the vector consisting of the availabilities and requirements of k^{th} sub-problem.

R_o the matrix consisting of the first m_o columns of B^{-1}, m^o denotes the number of elements of b, B be the current basis matrix.

c^k the vector of first objective coefficients of k^{th} sub-problem .

d^k the vector of second objective coefficients of k^{th} sub-problem .

c_B the corresponding vector of basic variables coefficients.

N the number of sub- problems.

The following section presents an algorithm for determining all non dominated extreme points for the (BMTSP 3) model from which the solution for (BMTSP 1) and (BMTSP 2) models can be deduced from it as special cases.

Assuming that independent constraints are:

D^k, k= 1,2,…,N is the technological matrix of the kth stage activity. D^k is $(m_k + n_k) * (m_k + n_k)$ matrix, N is the number of stages, mk is the number of sources at k^{th} stage, n^k is the number of destinations.

b^k is the column vector consisting of the availabilities and requirements of the k^{th} sub-problem, bk is $(m_k + n_k)$ * 1 column vector. It follows that each set of independent constraints can be written as:

$D^k x^k = b^k$, k = 1,2,…,N. x^k represent the vector of the corresponding variables, x^k is $(m_k + n_k)$ *1 column vector.

Assuming that common constraints are:

A^k which represents the technogical matrix of k^{th} stage activity, A_k is $m_0 * (m_k * n_k)$ matrix, m_0 is the number of common constraints. b^0 is the corresponding common resources vector which canbe written as m_0*1.

This gives: $A^1 x^1 + A^2x^2 + \ldots\ldots + A^k x^k + \ldots\ldots + A^N x^N = b^0$

Assuming that the objective functions are:

c^K which represent the vector of the first criterion coefficients for the k^{th} stage activity, c^k is $1*(m_k*n_k)$ row vector.

d^k represent the vector of the second criterion coefficients for the k^{th} stage activity, d^k is $1*(m_k*n_k)$ row vector.

Let: For the master program:

B be the basic matrix associated with the current basic solution, B is (mo*N) * (m_o+N) matrix.

C_B the row vector of the corresponding coefficients in the objective function, C_B is $1*(m_o+N)$ row vector.

R_o the matrix of size $(m_o + N)*m_o$ consisting of the first mo columns of B^{-1}, and

v_j the $(m_o + j)$th column of the same matrix B^{-1}

The algorithm presented here is divided into two phases.

Phase 1: To determine the non-dominated extreme points in the objective space. This algorithm is validated by the following theorem [1].

- *Theorem*

Point $z^{(q)} = \left(z_1^{(q)}, z_2^{(q)}\right)$ in a non-dominated extreme point is the objective space if and only if z(q) is recorded by the algorithm.

Phase II: The decomposition algorithm can be found in [7]. Since the special structure of the (BMTSP 3) model may allow the determination of the optimal solution by decomposing the problem into small sub-problems then by solving those sub-problems almost independently, and the decomposition algorithm for solving large scale linear programming problems utilizing the special nature of transshipment problem can be used to solve it.

Phase I:

Step 1: From phase II, we can find:

$$z_1^{(1)} = Min.\ (z_1 / x\ \varepsilon\ M)$$

$$z_2^{(1)} = Min.\ (z_2 / z_1 = z_1^{(1)}\ and\ x\ \varepsilon\ M)$$

$z_1^{(1)}$ and $z_2^{(1)}$ are obtained and q is set to 1. Similarly, we can find:

$$z_2^{(2)} = Min.\ (z_2 / x\ \varepsilon\ M)$$

$$z_1^{(2)} = Min.\ (z_1 / z_2 = z_2^{(2)}\ and\ x\ \varepsilon\ M)$$

If $(z_1^{(2)}, z_2^{(2)}) = (z_1^{(1)}, z_2^{(1)})$, stop.

Otherwise record $(z_1^{(2)}, z_2^{(2)})$ and set $q = q+1$

Defines sets L = {(1,2)} and E = ϕ, and go to step 2.

Step 2: Choose an element $(r,s) \in L$ and set

$$a_1^{(r,s)} = \left| z_2^{(s)} - z_2^{(r)} \right| \quad \text{and}$$

$$a_2^{(r,s)} = \left| z_1^{(s)} - z_1^{(r)} \right| \quad \text{and}$$

Go to phase II to obtain the optimal solution $(\overline{x^k}$, k=1,2,..,N) to the multistage transshipment problem.

$$\text{Minimize} \sum_{k=1}^{N} \sum_{i_k, j_k} (e_1^{(r,s)} c_{i_k j_k}^k + a_2^{(r,s)} d_{i_k j_k}^k) x_{i_k j_k}^k$$

Subject to

$$x^k \varepsilon M, x^k \geq o, \quad k = 1,2,.., N$$

If there are alternative optima, choose an optimal solution $\overline{x^k}$, k=1,2,..,N, for which

$$\sum_{k=1}^{N} \sum_{i_k, j_k} (c_{i_k j_k}^k \, x_{i_k j_k}^{-k} \; \min .)$$

$$\text{Let } \overline{z_1} = \sum_{k=1}^{N} \sum_{i_k, j_k} c_{i_k j_k}^k \, x_{i_k j_k}^{-k} \quad \text{and}$$

$$\overline{z_2} = \sum_{k=1}^{N} \sum_{i_k, j_k} d_{i_k j_k}^k \, x_{i_k j_k}^{-k}$$

If $(\overline{z_1}, \overline{z_2})$ is equal to $(z_1^{(r)}, z_2^{(r)})$ or $(z_1^{(s)}, z_2^{(s)})$

Set E = E ∪ {(r,s)} and go to step 3.

Otherwise record $(z_1^{(q)}, z_2^{(q)})$ such that

$z_1^{(q)} = \overline{z_1}$, $z_2^{(q)} = \overline{z}_2$ *and set* $q = q+1,$

L = L ∪ {(r,q)}, (q,s)} and go to step 3.

Step 3 : Set L = L - {(r-s)}. If L = ϕ, stop.

Otherwise go to step 2.

Phase II:

Step 1 : Reduce the original problem to the modified form in terms of the new variables β^k

Step 2 : Find an initial basic feasible solution to the modified problem.

Step 3 : Solve the sub-problems

$$w^k = (c^k OR \; d^k - c_B \;\; R_o \;\; A^k) \; x^k$$

Subject to:

$$D^k \;\; x^k = b^k,$$

$$x^k \geq o \, , k = 1,2,..., N.$$

Note: c^k is used with the first criteria, and d^k is used with the second criteria.

In order to obtain $\hat{x}_l^k$ and w^{*k} by using the transportation technique, go to step 4.

Step 4 : For the current iteration, find:

$$\rho^k = \overset{*k}{w} - c_B \;\; v^k \; , k = 1,2,..., N,$$

Then determine $\rho = \underset{k}{Min} \, (\rho^k)$

If $\rho \geq o$, the current solution is optimal and the process can be terminated, the optimal solution to multistage transportation problem is:

$$x^k = \sum_{L=1}^{L} \beta_L^K \;\; \overset{\wedge K}{xl}, \;\; k = 1,2,..., N$$

Otherwise, go to step 5.

Step 5 : Introduce the variable β_L^k corresponding to ρ into the basic solution. Determine the leaving variable using the feasibility condition and compute the next B^{-1} using the revised simplex method technique, go to step 3.

- *Illustrative Example*

The suggested algorithm for solving problem of the type BMTSP 3 is illustrated in the following example:

Consider the following bi-criteria two-stage transshipment problem. For each stage the availabilities, requirements, costs and deteriorations for each stage are given by:

$$a_1^1 = 6, \;\; a_2^1 = 4, \;\; a_3^1 = 2, \;\; b_1^1 = a_1^2 = 9, \; b_2^1 = a_2^2 = 3,$$

$$b_1^2 = 6, \;\; b_2^2 = 2, \; b_3^2 = 4$$

Table 1-1 : Transportation cost at stages (1)

	D_1^1	D_2^1	S_1^1	S_2^1	S_3^1
S_1^1	5	4	0	2	1
S_2^1	10	8	1	0	4
S_3^1	9	9	3	2	0
D_1^1	0	1	5	9	9
D_2^1	3	0	4	6	7

Table 1-2 : Transportation cost at stages (2)

	D_1^2	D_2^2	D_3^2	S_1^2	S_2^2
S_1^2	4	3	3	0	3
S_2^2	8	4	7	2	0
D_1^2	0	2	4	8	7
D_2^2	4	0	3	3	5
D_3^2	3	4	0	4	9

Global Journal of Researches in Engineering (B) Volume XIV Issue IV Version I Year 2014

Table 2-1 : Deterioration cost at stages (1)

	D^1_1	D^1_2	S^1_1	S^1_2	S^1_3
S^1_1	3	6	0	1	4
S^1_2	7	9	3	0	6
S^1_3	12	11	4	6	0
D^1_1	0	3	7	11	12
D^1_2	5	0	7	8	8

Table 2-2 : Deterioration cost at stages (2)

	D^2_1	D^2_2	D^2_3	S^2_1	S^2_2
S^2_1	6	5	5	0	6
S^2_2	11	6	9	5	0
D^2_1	0	4	6	11	9
D^2_2	6	0	5	4	7
D^2_3	5	7	0	6	11

One requirement is added to the above problem:

It is required that the quantity shipped from the first source to the first destination in the first stage is equal to the quantity shipped from the first source to the first destination in the second stage.

The mathematical model is given as follows:

Minimize

$$
\begin{aligned}
{}^{1} = {} & 5x^1_{11} + 4x^1_{12} + 0x^1_{13} + 2x^1_{14} + x^1_{15} \\
& + 10x^1_{21} + 8x^1_{22} + x^1_{23} + 0x^1_{24} + 4x^1_{25} \\
& + 9x^1_{31} + 9x^1_{32} + 3x^1_{33} + 2x^1_{34} + 0x^1_{35} \\
& + 0x^1_{41} + x^1_{42} + 5x^1_{43} + 9x^1_{44} + 9x^1_{45} \\
& + 3x^1_{51} + 0x^1_{52} + 4x^1_{53} + 6x^1_{54} + 7x^1_{55} \\
& + 4x^2_{11} + 3x^2_{12} + 2x^2_{13} + 0x^2_{14} + 3x^2_{15} \\
& + 8x^2_{21} + 4x^2_{22} + 7x^2_{23} + 2x^2_{24} + 0x^2_{25} \\
& + 0x^2_{31} + 2x^2_{32} + 4x^2_{33} + 8x^2_{34} + 7x^2_{35} \\
& + 4x^2_{41} + 0x^2_{42} + 3x^2_{43} + 3x^2_{44} + 5x^2_{45} \\
& + 3x^2_{51} + 4x^2_{52} + 0x^2_{53} + 4x^2_{54} + 9x^2_{55}
\end{aligned}
$$

$$
\begin{aligned}
Z^2 = {} & 3x^1_{11} + 6x^1_{12} + 0x^1_{13} + 1x^1_{14} + 4x^1_{15} \\
& + 7x^1_{21} + 9x^1_{22} + 3x^1_{23} + 0x^1_{24} + 6x^1_{25} \\
& + 12x^1_{31} + 11x^1_{32} + 4x^1_{33} + 6x^1_{34} + 0x^1_{35} \\
& + 0x^1_{41} + 3x^1_{42} + 7x^1_{43} + 11x^1_{44} + 12x^1_{45} \\
& + 5x^1_{51} + 0x^1_{52} + 7x^1_{53} + 8x^1_{54} + 8x^1_{55} \\
& + 6x^2_{11} + 5x^2_{12} + 5x^2_{13} + 0x^2_{14} + 6x^2_{15} \\
& + 11x^2_{21} + 6x^2_{22} + 9x^2_{23} + 5x^2_{24} + 0x^2_{25} \\
& + 0x^2_{31} + 4x^2_{32} + 6x^2_{33} + 11x^2_{34} + 9x^2_{35} \\
& + 6x^2_{41} + 0x^2_{42} + 5x^2_{43} + 4x^2_{44} + 7x^2_{45} \\
& + 5x^2_{51} + 7x^2_{52} + 0x^2_{53} + 6x^2_{54} + 11x^2_{55}
\end{aligned}
$$

Subject to:

$$
\begin{aligned}
& x^1_{11} = x^2_{11} \\
& x^1_{11} + x^1_{12} + x^1_{13} + x^1_{14} + x^1_{15} = 18 \\
& x^1_{21} + x^1_{22} + x^1_{23} + x^1_{24} + x^1_{25} = 16 \\
& x^1_{31} + x^1_{32} + x^1_{33} + x^1_{34} + x^1_{35} = 14 \\
& x^1_{41} + x^1_{42} + x^1_{43} + x^1_{44} + x^1_{45} = 12 \\
& x^1_{51} + x^1_{52} + x^1_{53} + x^1_{54} + x^1_{55} = 12 \\
& x^1_{11} + x^1_{21} + x^1_{31} + x^1_{41} + x^1_{51} = 21 \\
& x^1_{12} + x^1_{22} + x^1_{32} + x^1_{42} + x^1_{52} = 15 \\
& x^1_{13} + x^1_{23} + x^1_{33} + x^1_{43} + x^1_{53} = 12 \\
& x^1_{14} + x^1_{24} + x^1_{34} + x^1_{44} + x^1_{54} = 12 \\
& x^1_{15} + x^1_{25} + x^1_{35} + x^1_{45} + x^1_{55} = 12 \\
& x^2_{11} + x^2_{12} + x^2_{13} + x^2_{14} + x^2_{15} = 21 \\
& x^2_{21} + x^2_{22} + x^2_{23} + x^2_{24} + x^2_{25} = 15 \\
& x^2_{31} + x^2_{32} + x^2_{33} + x^2_{34} + x^2_{35} = 12 \\
& x^2_{41} + x^2_{42} + x^2_{43} + x^2_{44} + x^2_{45} = 12 \\
& x^2_{51} + x^2_{52} + x^2_{53} + x^2_{54} + x^2_{55} = 12 \\
& x^2_{11} + x^2_{21} + x^2_{31} + x^2_{41} + x^2_{51} = 18 \\
& x^2_{12} + x^2_{22} + x^2_{32} + x^2_{42} + x^2_{52} = 14 \\
& x^2_{13} + x^2_{23} + x^2_{33} + x^2_{43} + x^2_{53} = 16 \\
& x^2_{14} + x^2_{24} + x^2_{34} + x^2_{44} + x^2_{54} = 12 \\
& x^2_{15} + x^2_{25} + x^2_{35} + x^2_{45} + x^2_{55} = 12
\end{aligned}
$$

Table 3 : Set of non dominated extreme points

Iteration	L	E	Recorded Point
1	{(1,2)}	ϕ	Z^1=(113,156)
2	{(1,2)}	ϕ	Z^2=(127,140)
3	{(1,3), (3,2)}	ϕ	Z^3=(121,141)
4	{(3,2), (1,4), (4,3)}	ϕ	Z^4=(115,149)
5	{(1,4), (4,3), (3,5), (5,2)}	ϕ	Z^5=(124,140)
6	{(1,4), (4,3), (3,5)}	{(5,2)}	Z^6=(124,140)
7	{(1,4), (4,3)}	{(5,2), (3,5)}	Z^7=(124,140)
8	{(1,4)}	{(5,2), (3,5), (4,3)}	Z^8=(115,149)
9	ϕ	{(5,2), (3,5), (4,3), (1,4)}	Z^9=(113,156)

Table 4 : Non zero value of X_{ij} for each non dominated point

Iteration	Non dominated (Z_1, Z_2)	Non zero value of X_{ij}
1	$Z^1=(113,156)$	$X^1_{11}=6, X^1_{12}=4, X^1_{13}=8, X^1_{23}=4, X^1_{24}=12, X^1_{31}=2, X^1_{35}=12, X^1_{41}=12, X^1_{51}=1, X^1_{52}=11, X^2_{11}=6, X^2_{13}=4, X^2_{14}=11, X^2_{22}=2, X^2_{24}=1, X^2_{25}=12, X^2_{31}=12, X^2_{42}=12, X^2_{53}=12.$
2	$Z^2=(127,140)$	$X^1_{11}=6, X^1_{12}=2, X^1_{13}=10, X^1_{21}=3, X^1_{22}=1, X^1_{24}=12, X^1_{33}=2, X^1_{35}=12, X^1_{41}=12, X^1_{52}=12, X^2_{11}=6, X^2_{13}=3, X^2_{14}=12, X^2_{22}=2, X^2_{23}=1, X^2_{25}=12, X^2_{31}=12, X^2_{42}=12, X^2_{53}=12.$
3	$Z^3=(121,141)$	$X^1_{11}=6, X^1_{12}=3, X^1_{13}=9, X^1_{21}=3, X^1_{23}=1, X^1_{24}=12, X^1_{33}=2, X^1_{35}=12, X^1_{41}=12, X^1_{52}=12, X^2_{11}=6, X^2_{13}=4, X^2_{14}=11, X^2_{22}=2, X^2_{24}=1, X^2_{25}=12, X^2_{31}=12, X^2_{42}=12, X^2_{53}=12.$
4	$Z^4=(115,149)$	$X^1_{11}=6, X^1_{12}=3, X^1_{13}=9, X^1_{21}=1, X^1_{23}=3, X^1_{24}=12, X^1_{31}=2, X^1_{35}=12, X^1_{41}=12, X^1_{52}=12, X^2_{11}=6, X^2_{13}=4, X^2_{14}=11, X^2_{22}=2, X^2_{24}=1, X^2_{25}=12, X^2_{31}=12, X^2_{42}=12, X^2_{53}=12.$
5	$Z^5=(124,140)$	$X^1_{11}=6, X^1_{12}=3, X^1_{13}=9, X^1_{21}=3, X^1_{23}=1, X^1_{24}=12, X^1_{33}=2, X^1_{35}=12, X^1_{41}=12, X^1_{52}=12, X^2_{11}=6, X^2_{13}=3, X^2_{14}=12, X^2_{22}=2, X^2_{23}=1, X^2_{25}=12, X^2_{31}=12, X^2_{42}=12, X^2_{53}=12.$
6	$Z^6=(124,140)$	$X^1_{11}=6, X^1_{12}=3, X^1_{13}=9, X^1_{21}=3, X^1_{23}=1, X^1_{24}=12, X^1_{33}=2, X^1_{35}=12, X^1_{41}=12, X^1_{52}=12, X^2_{11}=6, X^2_{13}=3, X^2_{14}=12, X^2_{22}=2, X^2_{23}=1, X^2_{25}=12, X^2_{31}=12, X^2_{42}=12, X^2_{53}=12.$
7	$Z^7=(124,140)$	$X^1_{11}=6, X^1_{12}=3, X^1_{13}=9, X^1_{21}=3, X^1_{23}=1, X^1_{24}=12, X^1_{33}=2, X^1_{35}=12, X^1_{41}=12, X^1_{52}=12, X^2_{11}=6, X^2_{13}=3, X^2_{14}=12, X^2_{22}=2, X^2_{23}=1, X^2_{25}=12, X^2_{31}=12, X^2_{42}=12, X^2_{53}=12.$
8	$Z^8=(115,149)$	$X^1_{11}=6, X^1_{12}=3, X^1_{13}=9, X^1_{21}=1, X^1_{23}=3, X^1_{24}=12, X^1_{31}=2, X^1_{35}=12, X^1_{41}=12, X^1_{52}=12, X^2_{11}=6, X^2_{13}=4, X^2_{14}=11, X^2_{22}=2, X^2_{24}=1, X^2_{25}=12, X^2_{31}=12, X^2_{42}=12, X^2_{53}=12.$
9	$Z^9=(113,156)$	$X^1_{11}=6, X^1_{12}=4, X^1_{13}=8, X^1_{23}=4, X^1_{24}=12, X^1_{31}=2, X^1_{35}=12, X^1_{41}=12, X^1_{51}=1, X^1_{52}=11, X^2_{11}=6, X^2_{13}=4, X^2_{14}=11, X^2_{22}=2, X^2_{24}=1, X^2_{25}=12, X^2_{31}=12, X^2_{42}=12, X^2_{53}=12.$

III. Conclusion

An algorithm for solving a certain class of bi-criteria multistage transportation problems with transshipment (BMTSP) is presented. The presented algorithm enables solving such problems more realistically. It can be used for determining all efficient extreme points. The main advantage of this approach is that the bi-criteria two stage transshipment problem can be solved using the standard form of a transshipment problem at each iteration. Goods transportation may not operate always directly among suppliers and customers. In such problems, it is possible to optimize the transshipment problem into two stages. From the application, decision maker will have all efficient extreme points and their related distributions. Therefore, any point can be chosen, which will provide their policy.

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Global Journal of Researches in Engineering: B
Automotive Engineering
Volume 14 Issue 4 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

A Comparative Study of Cost Estimation Models used for Preliminary Aircraft Design

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Abstract- Estimation of the direct operating cost (DOC), seat mile cost (SMC) and price of the aircraft, is an important aspect in commercial transport aircraft design. The operating costs are classified into two categories which are direct operating cost (DOC) and indirect operating cost (IOC). IOC is difficult to estimate well, since it depends on the services that the airline (customer) offered, and can vary considerably between operators. Therefore, DOC is useful and widely-used parameter for comparative analysis. Many methodologies have been developed to estimate DOC. There are three common methodologies that are in use in preliminary aircraft design. These models, namely the ATA, NASA and the AEA form the basis of cost estimation. In the preliminary aircraft design stage, cost estimates are required to evaluate the viability of the design being considered. This paper presents the cost estimation methodology of these three methods and compares the estimated costs for a range of current aircraft. The paper also presents a new empirical relationship for estimating the DOC.

Keywords: *aircraft design, aircraft cost estimation, doc methods, doc estimation.*

GJRE-B Classification : *FOR Code: 290203*

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Rashid Ali [α] & Omran Al-Shamma [σ]

Abstract- Estimation of the direct operating cost (DOC), seat mile cost (SMC) and price of the aircraft, is an important aspect in commercial transport aircraft design. The operating costs are classified into two categories which are direct operating cost (DOC) and indirect operating cost (IOC). IOC is difficult to estimate well, since it depends on the services that the airline (customer) offered, and can vary considerably between operators. Therefore, DOC is useful and widely-used parameter for comparative analysis. Many methodologies have been developed to estimate DOC. There are three common methodologies that are in use in preliminary aircraft design. These models, namely the ATA, NASA and the AEA form the basis of cost estimation. In the preliminary aircraft design stage, cost estimates are required to evaluate the viability of the design being considered. This paper presents the cost estimation methodology of these three methods and compares the estimated costs for a range of current aircraft. The paper also presents a new empirical relationship for estimating the DOC.

Keywords: *aircraft design, aircraft cost estimation, doc methods, doc estimation.*

Nomenclature

C_{AC} = aircraft cost
C_{AF} = airframe cost
C_{AFc} = airframe cost per kilogram
$C_{(al)_{kh}}$ = airframe labour manhours per flight hour
$C_{(al)_{kc}}$ = airframe labour manhours per flight cycle
$C_{(am)_{kh}}$ = airframe material cost per flight hour
$C_{(am)_{kc}}$ = airframe material cost per flight cycle
$C_{(el)_{kh}}$ = engine labour manhours per flight hour
$C_{(el)_{kc}}$ = engine labour manhours per flight cycle
$C_{(em)_{kh}}$ = engine material cost per flight hour
$C_{(em)_{kc}}$ = engine material cost per flight cycle
C_{al} = airframe labour maintenance cost per flight
C_{am} = airframe maintenance cost per flight
C_{amm} = airframe material maintenance cost per flight
C_{bur} = maintenance burden cost
C_{cc} = cabin crew cost
C_{dp} = depreciation cost per flight
C_{el} = engine labour maintenance cost per flight
C_{em} = engines maintenance cost per flight
C_{emm} = engine material maintenance cost per flight
C_{eng} = engine cost
C_{engc} = engine cost per one pound thrust
C_{fc} = flight crew cost
C_{fu} = fuel cost per gallone
C_{fuel} = fuel cost per flight
C_{grd} = ground − handling cost per flight
C_{ins} = insurance cost per flight
C_{int} = interest cost per flight
C_{lf} = landing fees per flight
C_{lr} = labour cost per hour
C_{maint} = total maintenance cost
C_{nav} = navigational charges per flight
C_{oil} = oil cost per gallone
E_{bpr} = engine bypass ratio
E_{oapr} = overall compressor ratio
F_i = international salary premium (= 1 for domestic, = 1.1 for international flights
N_c = number of compressor stages per engine
N_{cc} = number of flight attendants
N_{eng} = number of engines
N_{fc} = number of flight crew
P_{af} = airframe life (Liebeck assumes 15 years)
P_{eng} = engine life (Liebeck assumes 15 years)
R = residual aircraft value (%)
R_{ins} = insurance rate
R_{int} = interest rate
S_{af} = airframe spares (assume $0.06 \times$ airframe cost)
S_{eng} = engine spares (assume $0.23 \times$ engine cost)
T_{eng} = engine thrust
U = aircraft utilization (hours/year)
m_{af} = aircraft empty mass minus engines mass (lbs)
m_{fuel} = design fuel mass
m_{lan} = landing aircraft mass
m_{oe} = aircraft operating empty mass
m_{pay} = payload mass
m_{to} = maximum takeoff weight
s_l = main mission stage length
t_B = block time in hours
t_f = flight time in hours

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I. Introduction

Direct operating cost and seat mile cost are significant parameters in evaluating competitive aircraft designs. Although the rule of thumb is that the aircraft cost depends mainly on aircraft empty weight, but occasionally this is not correct. For example, when new technologies and materials (e.g. composite) are used, it has an effect of reducing the aircraft weight, but may incur an increased production cost. Therefore, manufacturers always pick the design and price that maximizes their own return. This requires better estimates of the operating costs (OC) and good measure of the market elasticity. Customers are interested in cost savings, not just low aircraft price at the time of purchase but also throughout the lifetime of the aircraft [1]. More specifically, one pays for a pound of aluminium in the wing once, but a pound of fuel on every flight [2].

Aircraft operating costs consist of many items such as depreciation, insurance, maintenance, fuel burn, flight crew, cabin crew, landing fees, and passenger services. These items are grouped into two main categories which are direct operating cost (DOC) and indirect operating cost (IOC). IOC is difficult to estimate well, since it depends on the services that the airline (customer) offers [2]. Therefore, DOC and aircraft price is useful and widely-used parameter for comparative analysis.

In 1944, the Air Transportation Association of America (ATA) developed the first set of empirical equations to estimate DOC. It continued periodically to revise these formulae to match current statistical cost data. The last updated version was published in 1967 [3]. Many methodologies have been developed thereafter [4, 5]. Purpose of applying a standard methodology to estimate DOC is to enable efficient means for comparing the DOC of the competitive aircraft under set of conditions, and to enable both the manufacturer and the customer in assessing the economic suitability of the aircraft operation on a given route. For educational environments, ATA pointed out that it *"must essentially be general in scope, and for simplicity should preferably employ standard formulae into which the values appropriate to the aircraft under study are sub¬stituted"* [3]. Typically, aircraft manufacturers use standard methodologies in their cost comparisons, while customers (airlines) always generate their own methodologies based on many things that may not be accounted for, such as fleet size, route structure, accounting procedures, etc, or capitalize certain costs which then can be reported in depreciation or amortization cost figures.

II. Cost Estimation

Cost estimation model is an important aspect in educational commercial aircraft design, especially when the techniques are embedded in an automated design tool. It has been employed in interactive aircraft design software (iADS) [6]. This paper encapsulates three common methodologies and evaluates their effectiveness in estimating the DOC as proposed by ATA [3], NASA [7], and AEA [8]. Their empirical formulae are explained in details. ATA, the professional society of airline business in the U.S., used industry-wide statistical data to develop a standard methodology for estimating comparative DOC of jet aircraft. NASA's methodology is an estimation methodology known as DOC+I (Direct Operating Cost plus Interest). It is based on the work done by Liebeck [7], who was able to draw upon the operating costs of McDonnell Douglas aircraft in commercial service up until 1993. It is therefore based on a more recent set of data which reflect airline costs in a deregulated environment. AEA methodology has been accepted as the basis for comparison in Europe. These methodologies depend initially on estimating aircraft price (capital cost). It has a great impact on DOC. Estimating aircraft price in the early stages of the aircraft design requires an investigation of the actual data available. Prices of the current Boeing [9] and Airbus [10] aircraft for the year 2010 are shown as Figure 1, as a function of their operating empty weight. These prices have been shown as an average, since the exact price of a given aircraft depends upon special equipment particular to different buyers. It must be noted that year 2010 is chosen as a reference year due to the last available published data. Although some of DOC items have up-to-date values such as fuel price, others such as labour cost have not. The flexibility of the used models makes them applicable to be used for any year by applying a simple inflation factor. Simple inflation is applied by multiplying each DOC component in the model by the consumer price index (CPI) for the required year divided by the CPI for the reference year (2010). Aircraft price is evaluated by Sforza [11] in terms of \$/lb. It is being proposed here that aircraft price (in \$) should be evaluated as a function of the operating empty weight m_{oe} kg directly as defined by the proposed empirical formula (1) & (2).

$$C_{AC} = 10^6 \times (1.18 \times m_{oe}^{0.48} - 116),\ if\ m_{oe} \geq 10000\,kg \tag{1}$$

$$C_{AC} = -0.002695 \times {m_{oe}}^2 + 1967 \times m_{oe} - 2158000,\ if\ m_{oe} < 10000\,kg \tag{2}$$

Similar procedure was proposed by Kroo [12] to estimate the price of the aircraft's engine as a function of engine thrust, as shown in Figure 2. The equation is based on prices as in 1990 and should be corrected to prices of 2010 by applying a simple inflation multiplier (1.76) which is the ratio of the CPI for year 2010 to that for 1990. Ref. [13] presents some deflators that are used in the aerospace industry while more extensive information on the CPI and other economic factors may be found in [14]. The formula for engine price (in \$) is:

$$C_{eng} = 1.76 \times 82.5 \times T_{eng} \quad (3)$$

III. Doc Components

DOC is expressed in terms of \$/hour, \$/mile, ¢/seat-mile, or for cargo aircraft in terms of ¢/ton-mile. Costs in terms of \$/mile indicate the maximum loss with a partially filled aircraft, while costs per unit productivity such as ¢/seat-mile, or ¢/ton-mile are indicative of the fare that must be charged with reasonable load factors. DOC breaks down into its components and is explained in the following sub-sections. Each component cost is computed using the three methodologies: ATA, NASA, and AEA, the respective formulae are presented for completeness. Aircraft speed is one of the important factors in calculating DOC components. It is calculated as by dividing the stage length by the block time [3]. The block time being composed of the sum of ground manoeuvre time (in hours – which includes one minute for takeoff = 0.25 for all aircraft), climb time, cruise time, descend time, and the time for air manoeuvre (which is six minutes - no credit for distance = 0.1 for all aircraft).

It must be pointed out here that all component costs are per trip and some of them are based on evaluation of the annual utilization (U) of the aircraft, which in turn depends mainly on the customer and its route (i.e. the range). The latter can be derived in terms of block hour time t_B.From the original ATA graph [3], the following formula represents the relationship between the block time and the annual utilization:

$$U = 6100 - 3100 \times {t_B}^{-0.3342} \quad (4)$$

MIT [15] developed the daily utilization for a number of US airliners in year 2006. It is based on average utilization of 10.64 hours/day, which is approximated to an annual utilization of about 3800 hours/year. It seems approximately equal to the average of the original utilisation proposed by the ATA method.

NASA suggests values of utilization as trips per year, for short range aircraft 2100 trips/year, medium range aircraft = 625 trips/year and for long range aircraft 480 trips/year. For short and medium ranges, AEA utilization(U)formula in terms of hours/year is:

$$U = \left(\frac{3750}{t_B + 0.5}\right) \times t_B \quad (5)$$

While for long range, it is assumed to be equal to 4800 hours/year. Equations (4) and (5) adjust the utilisation based on the block time, rather than adopt a fixed value, as outlined by the NASA method.

a) Depreciation

The Depreciation of the capital value of an aircraft is dependent to a large degree on the individual airline and its competitive conditions as the aircraft is maintained in a fully airworthy condition throughout its life. ATA depreciation period (D_a) is 12 years and 0% is the residual value for subsonic aircraft and its components [3]. ATA depreciation formula is:

$$C_{dp} = \frac{(C_{AC} + 0.1 \times C_{AF} + 0.4 \times C_{eng}) \times t_B}{D_a \times U} \quad (6)$$

Corresponding formula for NASA methodology is:

$$C_{dp} = \frac{C_{dp\,year}}{U} \quad (7)$$

Where $C_{dp_{year}}$ is evaluated using the following formula:

$$C_{dp_{year}} = (1 - R) \times \left(\frac{C_{AF}}{P_{af}}\right) + S_{af} \times \left(\frac{C_{AF}}{P_{af}}\right) + \frac{C_{eng}}{P_{af}} + S_{eng} \times \left(\frac{C_{eng}}{P_{eng}}\right) \quad (8)$$

AEA suggests a ten-aircraft fleet with 14-year lifespan and a residual value (R) of 10% of the total investment. i.e.:

$$C_{dp} = \frac{0.9 \times t_B (C_{AC} + 0.1 \times C_{AF} + 0.3 \times C_{eng})}{14 \times U} \quad (9)$$

b) Hull Insurance

ATA insurance value per trip [3] is determined as follows:

$$C_{ins} = \frac{t_B \times R_{ins} \times C_{AC}}{U} \quad (10)$$

Where R_{ins} is typically equal to 0.0023 [16].

NASA formula is:

$$C_{ins} = \frac{0.0035 \times C_{AC}}{U} \quad (11)$$

AEA formula is:

$$C_{ins} = \frac{0.005 \times C_{AC}}{U} \quad (12)$$

c) Interest

Although the original ATA method did not include the interest cost, most aircraft purchases nowadays are financed through the use of long-term debt and a down payment from company funds. For that reason, Hays [17], suggests the following AEA formula to be used in ATA methodology with R_{int} is typically = 0.07 [16]:

$$(C_{int})_{ATA} = \frac{t_B \times R_{int} \times (C_{AC} + 0.1 \times C_{AF} + 0.3 \times C_{eng})}{U} \quad (13)$$

$$(C_{int})_{NASA} = \frac{R_{int} \times (C_{AC} + 0.06 \times C_{AF} + 0.23 \times C_{eng})}{U} \quad (14)$$

Where R_{int} = 0.055[7].

AEA formula is similar to equation (11) with R_{int} = 0.053.

d) Flight Crew

ATA method for estimating the crew costs are based on the 1967 labour costs and the result must be updated to the 2010 prices. It is convenient to simply inflate the equation result by the ratio of consumer price index (CPI) in 2010 to that in 1967 which is:

$$(CPI)_{2010}/(CPI)_{1967} = 218.056/33.4 = 6.53$$

This factor modifies ATA formula to be including a multiplier for CPI of 100;

$$C_{fc} = t_B \times \left(\frac{0.326 \times m_{to}}{1000} + 653\right) \quad (15)$$

Whereas NASA's Equation, for estimating the crew costs is:

$$C_{fc} = t_B \times N_{fc} \times F_i \times \left(440 + \frac{0.532 \times m_{to}}{1000}\right) \quad (16)$$

Where m_{to} is in pounds.

AEA uses \$493 per block hour for a two-crew operation, i.e.:

$$C_{fc} = t_B \times 493 \quad (17)$$

e) Cabin Crew

In the ATA estimation method cabin crew costs are classified as indirect costs and hence, there is no formula for these costs. In the NASA methodology, the formula for cabin crew cost is:

$$C_{cc} = t_B \times N_{cc} \times C_{cc_b} \quad (18)$$

Where C_{cc_b} = base cabin crew cost of \$60/hr for domestic flights and \$78/hr for international flights.

AEA formula is similar to NASA except that AEA uses \$81/hr for C_{cc_b}.

f) Fuel and Oil

The current fuel prices may be found from IATA website [18]. A factor of 0.326 is used to convert 1kg of fuel weight to 1gal of volume for the reason that the density of Jet A fuel may be taken as 6.76 lbs/gal at standard conditions. On the other hand, examination of prices for turbine oil shows that it is around \$50/gal. Therefore, applying simple CPI inflation is sufficiently accurate and that the lubricating oils are not following the rise of fuel prices. ATA equation [3] for fuel and oil cost per trip (which includes 2% non revenue flying and assuming that the rate of consumption of oil is 0.135 lbs/hr/engine) is:

$$(C_{fuel})_{ATA} = 1.02 \times \left(m_{fuel} \times C_{f_b} + 0.135 \times t_B \times N_{eng} \times C_{oil}\right) \quad (19)$$

Where $C_{f_b} = 2.15\ \$/gal$ is the average value for year 2010, and $C_{oil} = 50\ \$/gal$.

Corresponding NASA and AEA Equation is:

$$C_{fuel} = \frac{m_{fuel} \times C_{f_b}}{\rho_f} \quad (20)$$

Where m_{fuel} is in pounds and excluding reserves, while $\rho_f = 6.7\ lbs/gal$.

g) Maintenance

This term includes labour and material costs for both airframe and engines. Furthermore, burden costs are also included i.e.:

$$C_{maint} = (C_{al} + C_{amm}) + (C_{el} + C_{emm}) + C_{bur} \quad (21)$$

i. *Airframe Labour Cost*

Labour cost associated for maintaining the airframe for the three methods is:

$$(C_{al})_{ATA} = \left(C_{(al)_{kh}} \times t_f + C_{(al)_{kc}}\right) \times C_{lr} \times M^{1/2} \quad (22)$$

Where $C_{(al)_{kc}} = \frac{0.05 \times m_{af}}{1000} + 6 - \frac{630}{\left(\frac{m_{af}}{1000} + 120\right)}$ (23)

$$C_{(al)_{kh}} = 0.59 \times C_{(al)_{kc}}\ ) \ , \quad (24)$$

$C_{lr} = \$42\ /hr$, and M=Cruise Mach Number

$$(C_{al})_{NASA} = \left(\left(1.26 + 1.774 \times \left(\frac{m_{af}}{10^5}\right) - 0.1071 \times \left(\frac{m_{af}}{10^5}\right)^2\right) \times t_B + \left(1.614 + 0.7227 \times \left(\frac{m_{af}}{10^5}\right) + 0.1204 \times \left(\frac{m_{af}}{10^5}\right)^2\right)\right) \times C_{lr} \quad (25)$$

Where, $C_{lr} = 25 \frac{\$}{hr}$

AEA estimates C_{al} as:

$$(C_{al})_{AEA} = \left(\frac{\left(0.09 \times m_{af} + 6.7 - \frac{350}{m_{af} + 75}\right) \times (0.8 + 0.68 \times (t_B - 0.25))}{t_B}\right) \times C_{lr} \quad (26)$$

Where, $C_{lr} = 63 \frac{\$}{hr}$

ii. *Airframe Material Cost*

ATA estimation of C_{amm} is based on:

$$C_{amm} = C_{(am)_{kh}} \times t_f + C_{(am)_{kc}} \quad (27)$$

Where $C_{(am)_{kh}} = \frac{3.08 \times C_{AF}}{10^6}$, and $C_{(am)_{kc}} = \frac{6.24 \times C_{AF}}{10^6}$

Whereas NASA estimates it as:

$$C_{amm} = \left(\left(12.39 + 29.8 \times \left(\frac{m_{af}}{10^5}\right) + 0.1806 \times \left(\frac{m_{af}}{10^5}\right)^2\right) \times t_B + \left(15.2 + 97.33 \times \left(\frac{m_{af}}{10^5}\right) - 2.862 \times \left(\frac{m_{af}}{10^5}\right)^2\right)\right) \times 1.509 \quad (28)$$

Correspondingly AEA determines it to be:

$$C_{amm} = \left(\frac{4.2 + 2.2 \times (t_B - 0.25)}{t_B}\right) \times \left(\frac{C_{AF}}{10^6}\right) \quad (29)$$

iii. *Engines Labour Cost*

For the three methodologies it is estimated as:

$$(C_{el})_{ATA} = \left(C_{(el)_{kh}} \times t_f + C_{(el)_{kc}}\right) \times C_{lr} \quad (30)$$

Where $C_{(el)_{kh}} = \left(0.6 + \frac{0.027 \times T_{eng}}{10^3}\right) \times N_{eng}$ (31) And $C_{(el)_{kc}} = \left(0.3 + \frac{0.03 \times T_{eng}}{10^3}\right) \times N_{eng}$ (32)

$$C_{el})_{NASA} = \left(0.645 + \left(\frac{0.05 \times T_{eng}}{10^4}\right) \times \left(0.566 + \frac{0.434}{t_B}\right)\right) \times N_{eng} \times C_{lr} \times t_B \quad (33)$$

$$(C_{el})_{AEA} = 0.21 \times C_1 \times C_3 \times C_{lr} \times \left(1 + T_{eng}\right)^{0.4} \quad (34)$$

Where $C_1 = 1.27 - 0.2 \times E_{bpr}{}^{0.2}$ (35)

And $C_3 = 0.032 \times N_c + K$ (36)

iv. *Engines Material Cost*

The material cost mainly being function of number of engines, block time, thrust and Initial engine cost, the three methods estimate it as:

$$(C_{emm})_{ATA} = C_{(em)_{kh}} \times t_f + C_{(em)_{kc}} \quad (37)$$

Where $C_{(em)_{kh}} = 2.5 \times N_{eng} \times \left(\frac{C_{eng}}{10^5}\right)$ (38)

and $C_{(em)_{kc}} = 2 \times N_{eng} \times \left(\frac{C_{eng}}{10^5}\right)$ (39)

$$(C_{emm})_{NASA} = \left(\left(25 + \left(\frac{0.05 \times T_{eng}}{10^4}\right)\right) \times \left(0.62 + \frac{0.38}{t_B}\right)\right) \times N_{eng} \times t_B \times 1.509 \quad (40)$$

$$(C_{em})_{AEA} = 2.56 \times C_1 \times (C_2 + C_3) \times \left(1 + T_{eng}\right)^{0.8} \quad (41)$$

Where $C_2 = 0.4 \times \left(\frac{E_{oapr}}{20}\right)^{1.3} + 0.4$ (42)

C_1 & C_3 as in Equation (35) & Equation (36) respectively.

Note that AEA total engine maintenance (labour + material) is:

$$(C_{em})_{AEA} = N_{eng} \times (C_{el} \times C_{emm}) \times \left(\frac{t_f + 1.3}{t_f - 0.25}\right) \quad (43)$$

v. *Maintenance Burden*

It is defined as labour and material overheads that contribute to overall maintenance costs through activities such as administration, controlling, monitoring, planning, testing, and tooling. It is also called "Indirect Maintenance Cost".

$$(C_{bur})_{ATA} = 1.8 \times (C_{al} + C_{el}) \quad (44)$$

$$(C_{bur})_{NASA} = 2 \times (C_{al} + C_{el}) \quad (45)$$

AEA has no burden cost included in its methodology.

h) Landing Fee

The landing fee is based on the maximum landing weight for domestic operations, or maximum takeoff gross weight for international operations. They may vary significantly in Europe, with possible additional fees such as for NO_x emissions or community noise, which are not included in DOC. ATA methodology categorized landing fee as an indirect cost, so for the other two methods it is determined to be:

$$(C_{lf})_{NASA} = 2.2 \times \frac{m_{land}}{1000} \quad for\ domestic\ operations \quad (46)$$

$$(C_{lf})_{NASA} = 6.25 \times \frac{m_{to}}{1000} \quad for\ international\ operations \quad (47)$$

Note that the weights (m_{lan}, m_{to}) are in pounds (*lbs*). AEA formula is:

$$(C_{lf})_{AEA} = 7.8 \times \frac{m_{to}}{1000} \quad (48)$$

i) Navigation Fee

The navigation fee is based on the first 500nm of a trip and the maximum takeoff gross weight of the aircraft, and applies to international flights only. ATA categorized this cost as an indirect cost, so not part of the DOC estimation, hence for the other two methods while NASA formula is:

$$(C_{nav})_{NASA} = 0.2 \times 500 \times \sqrt{\frac{m_{to}}{1000}} \quad (49)$$

Note: m_{to} is in pounds (*lbs*) for (49) & (50)

$$(C_{nav})_{AEA} = 0.5 \times \frac{s_l}{1000} \times \sqrt{\frac{\frac{m_{to}}{1000}}{50}} \quad (50)$$

j) Ground Handling Fee

This cost is included in DOC in AEA methodology only using the following formula:

$$C_{grd} = 0.1 \times m_{pay} \quad (51)$$

k) DOC

The total DOC per flight for the three methodologies therefore becomes:

$$(DOC/flight)_{ATA} = C_{dp} + C_{ins} + C_{fc} + C_{fuel} + C_{maint} \quad (52)$$

$$(DOC/flight)_{NASA} = C_{dp} + C_{ins} + C_{fc} + C_{fuel} + C_{maint} + C_{int} + C_{cc} + C_{lf} + C_{nav} \quad (53)$$

$$(DOC/flight)_{AEA} = C_{dp} + C_{ins} + C_{fc} + C_{fuel} + C_{maint} + C_{int} + C_{cc} + C_{lf} + C_{nav} + C_{grd} \quad (54)$$

Inspection of Equations (52), (53) and (54) reveals that $C_{int} + C_{cc} + C_{lf} + C_{nav}$ nav is the variation between the ATA and other methods, whereas C_{grd} is an additional factor when compared to the NASA method. This can be better seen from Figure 5. How will the numbers stack up?

IV. Results

To make a good comparison between ATA, NASA, and AEA methodologies, all of them have been applied to the current Airbus and Boeing aircraft. At a glance, AEA methodology gives the highest DOC values and in turn highest SMC as shown in Figure 3 and Figure 4, respectively. Although Figure 5 shows that AEA methodology has the highest DOC components and hence the highest value, it is better to break down the DOC into its main components and investigates each one.

The first component of DOC under consideration is the standing charges (or so-called the ownership) which consists of depreciation, insurance, and interest. These costs forms 30-40% of DOC and depend mainly on the annual utilization of the aircraft. Obviously, as the utilization increases, standing charges decreases. NASA methodology has the lowest average value, but the main drawback of NASA methodology is the ambiguous definitions of ranges (short, medium, and long) to find its utilization. On the other hand, if the aircraft is fully owned, interest is not included. From the engineering design point of view, Swan [19] suggests a simple way to overcome this problem by considering a monthly lease cost for new aircraft at about 0.8-0.9% of the aircraft price.

Maintenance cost is the second component that must be considered. In general, it makes up 13% of the DOC [19]. It is based on the utility of the aircraft which are in “steady-state maintenance”. That means the maintenance savings of the first five years for new designed aircraft have been finished and the second half-life maintenance cycles has been initiated. Although the most expensive inspections occur once each 3-4 years, the average cost is usually a rule of thumb. The maintenance cost forms 20-25% of DOC for ATA, 8% for NASA, and less than 1% for AEA. These huge differences make the comparison meaningless.

Flight crew cost is another major component of DOC. It is based on both flight time and maximum take-off weight for ATA and NASA, while it is based only on flight time for AEA methodology. Although there is no much difference between ATA and AEA, MIT [15] data agrees completely with ATA.

Fuel cost has changed rapidly in the last 10 years and forms a significant parameter that affected the aviation market. There is no difference noticed between the three methodologies. Although ATA added the oil used cost to the fuel cost, but it is form a very small difference that can be discounted.

Now, the question is which of the three methods is suitable, that can be used in preliminary design phase? The answer is simple. Any of them can be used. The question now is more specifically: Which of them estimates the DOC close to the actual value? First of all, it is a generally accepted fact that all manufacturers have their own proprietary methods for cost estimation, dependent upon their costing methods and operations, and are not available to the general public. On the other hand, all published data comes from the customers (airlines). Again each airline has their own categories to classify the various DOC components. For educational purposes, Al-Shamma [20] presented the three methods in his interactive aircraft design software (iADS). It is the designer’s responsibility to select one of them. The choice is somewhat dependent upon the various DOC components to be included. If for example, the design is a short range aircraft, then there is no navigation fee since it is applicable only to international long haul flights. For small business aircraft, no flight attendant cost required. If the requirements have no constraints on DOC components, only one method should used for all competitive aircraft designs. Figure 5 summarizes the DOC components for ATA, NASA, and AEA. It is shows that ATA has the lowest value, since landing fee, flight attendant cost, navigation fee, and ground handling cost are calculated as IOC. ATA methodology discounts the costs due to interest cost off.

Another methodology, which has been developed by Swan [19], was applied. It evaluates the DOC as a function of stage length and seat capacity. It is based on years 1999-2001 data, and need to apply an inflation factor of 1.266 to update data to year 2010. From Figure 6, it is clear that Swan’s methodology gives approximately the same average difference when compared with the ATA methodology.

Figure 7 shows the average value of the DOC obtained by the three methods against the maximum takeoff weight m_{to}. A simple equation that yields an acceptable result in the conceptual design stage can be determined to be:

$$DOC/Flight = -4.497 \times 10^{-7} \times {m_{to}}^2 + 0.9588 \times m_{to} - 33214 \quad (55)$$

V. Conclusion

DOC is a significant parameter in evaluating competitive aircraft designs and widely-used parameter for comparative analysis. ATA, NASA, and AEA are three common methodologies that are employed in the cost estimation for educational purposes and their choice depends upon the inclusion of various sub-categories that makes up the total DOC. All cost estimation methods have been applied to estimate the DOC and

SMC for the existing transport aircraft. The results show that ATA and NASA methodologies are close to each other. However, many factors (up to date) are required for DOC/SMC estimation. Hence, a very simple empirical relation was presented that estimates the DOC as a function of maximum takeoff weight, this can be very useful in conceptual or preliminary design phase.

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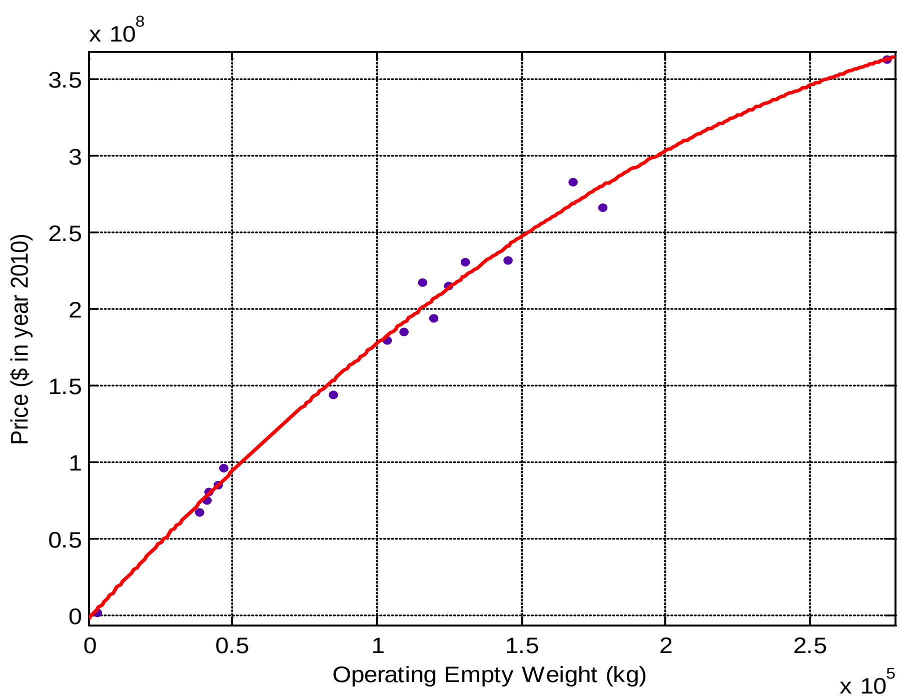

Figure 1 : Airbus & Boeing aircraft prices vs. Operating empty weight

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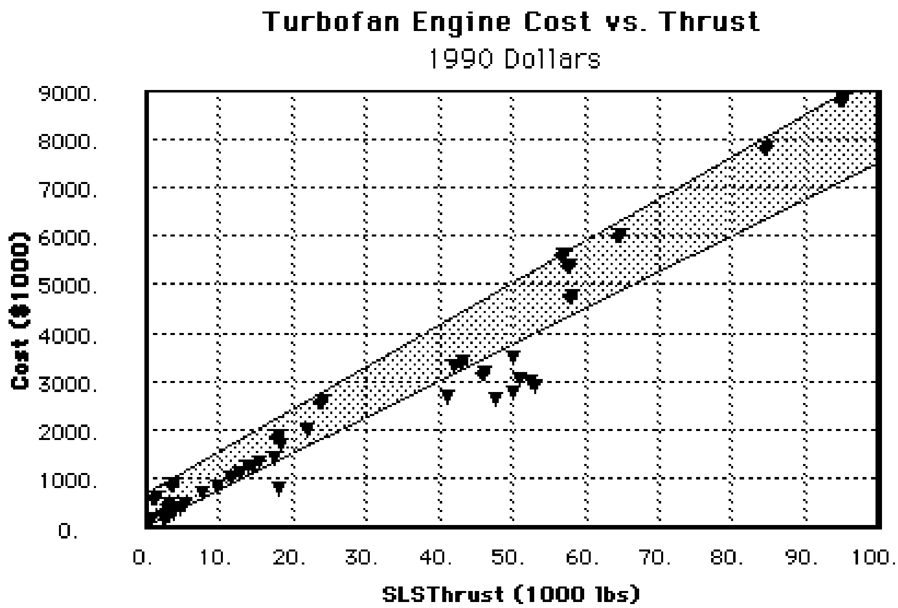

Figure 2 : Engine prices ($1990) vs. SLS thrust (lbs)

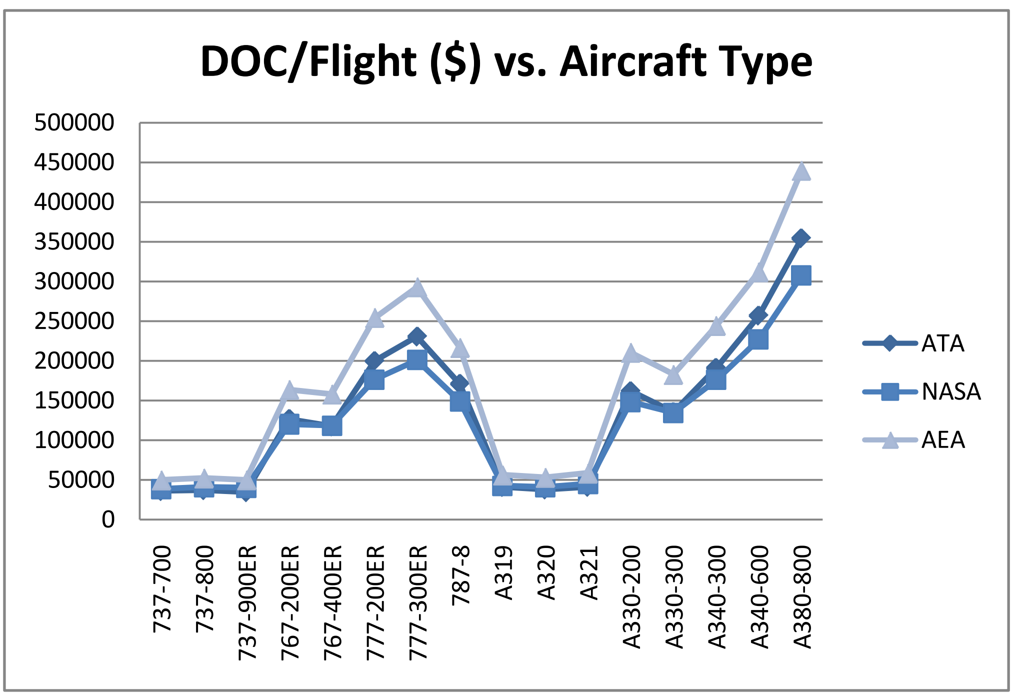

Figure 3 : DOC for ATA, NASA, and AEA methodologies

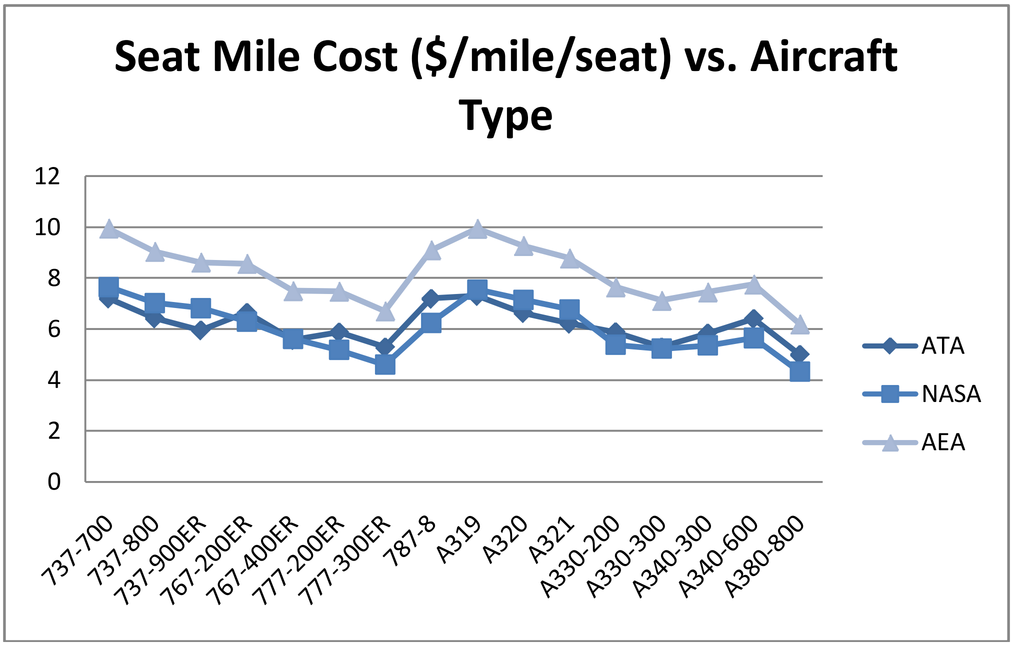

Figure 4 : SMC for ATA, NASA, and AEA methodologies

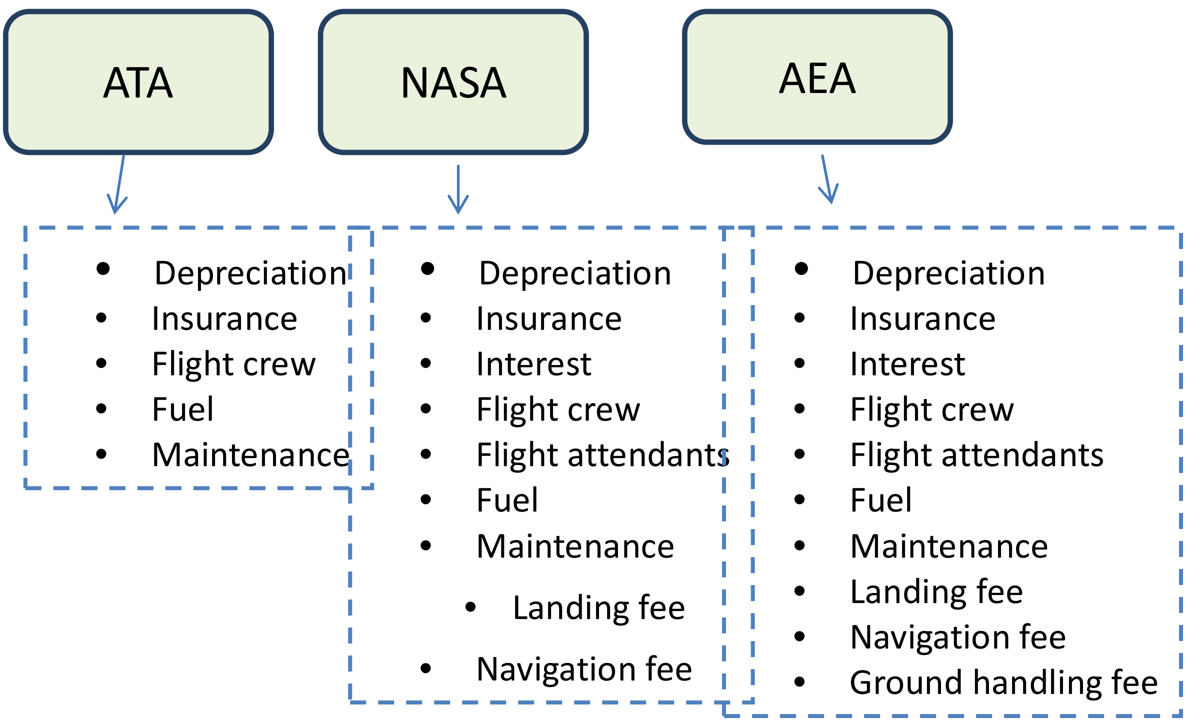

Figure 5 : DOC components for ATA, NASA, and AEA methods

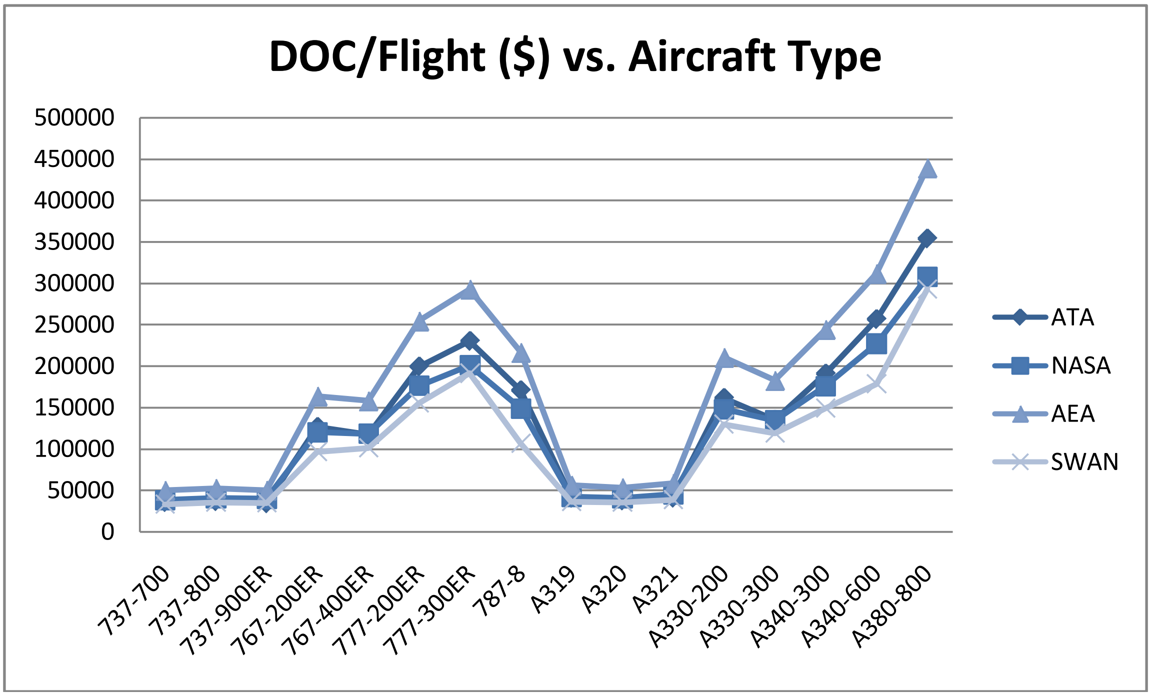

Figure 6 : DOC for ATA, NASA, AEA, and Swan methodologies

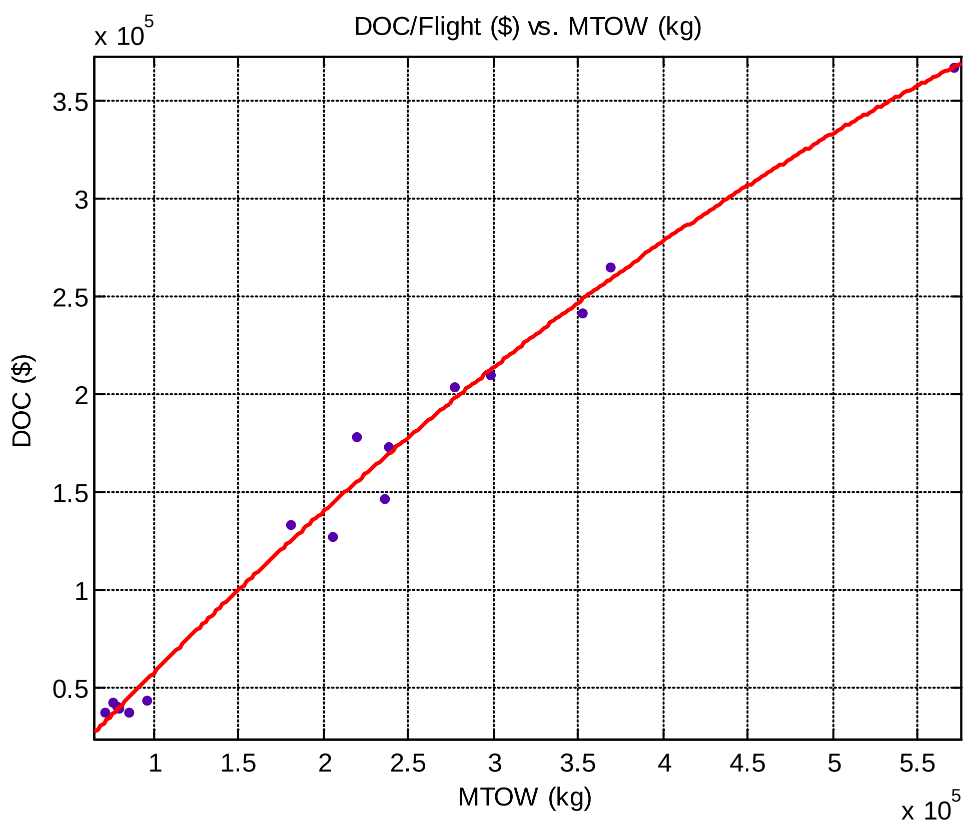

Figure 7 : Average DOC ((AEA+ATA+NASA)/3) versus Maximum takeoff weight (MTOW)

Global Journal of Researches in Engineering: B
Automotive Engineering
Volume 14 Issue 4 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Development a Single Zone Heat Release Model

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Abstract- Single zone heat release models can effectively be used to model diesel engine combustion process with acceptable degree of accuracy. These models are mainly depend on double Wiebe function which requires as many as six parameters in order to predict the heat release rate (HRR) accurately. However, Wiebe function does not look into the physical air fuel mixing process during the ignition delay (ID) which makes their predictions far from understanding the relation between the HRR and the physical interaction between air and fuel prior to combustion. Whitehouse and Way model covers the physical process since it deals with the mass of fuel injected and the partial pressure of oxygen in which the reaction rate is computed by an Arrhenius type expression. In this work, a strong relationship between HRR and air mass entrained during the ID has been shown. A new single zone heat release model based on Whitehouse and Way model for diesel engine has been developed in order to predict the HRR using standard diesel fuel. The new model has shown to give good results compared to experimental data.

Keywords: *heat release model, single zone model, whitehouse and way model, direct injection, diesel engine.*

GJRE-B Classification : *FOR Code: 090104p*

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Development a Single Zone Heat Release Model

J. Alrajhi [α], M. Alardhi [σ], A. Abed [ρ] & K. Alkhulaifi [ω]

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Keywords: heat release model, single zone model, whitehouse and way model, direct injection, diesel engine.

I. Introduction

Understanding the detailed physics and chemistry involved in the combustion processes of diesel engines are essential in predicting performance. Combustion process in diesel engines usually described [1] to consist of three main phases; premixed combustion, rate controlled diffusion combustion and late diffusion combustion. Experimental work is essential to understand the combustion process in diesel engines, and therefore provide relatively precise results for a specific test needed to ensure effective emission reduction. However, they are often uneconomical and time consuming. To overcome this, heat release models can effectively isolate one variable at a time and point out trends and causes.

Heat release models used for diesel engine combustion are classified into two groups, thermodynamic and multidimensional models. The thermodynamic models can be classified into three subgroups; single zone, two zones and multi zone models [2]. In single zone models, the entire volume of the combustion chamber is assumed to be a homogeneous mixture of air and combustion products and uniform in temperature. The first law of thermodynamics is used to calculate the mixture energy accounting for the enthalpy flux due to fuel injection. The fuel injected into the cylinder is assumed to mix instantaneously with the cylinder charge, which is assumed to behave as an ideal gas. At combustion, it then assumes that the fuel is burned immediately on injection into the combustion chamber [1, 3, 4, 5]. Often the measured pressure rise in an engine is used to tune the model or is used to provide a rate of heat release.

Although the assumption of homogeneous dispersion of the injected fuel is unrealistic, single zone models are valuable tools for quick analysis of the engine cycle and preliminary design computations.

One of the early single zone model was developed by Austen and Lyn [6]. This model emphasized the importance of the rate of fuel injection and indicated how the various phases of the combustion process may be dealt with mathematically. The model considered both the premixed and diffusion combustion phases while the combustion rate was obtained from the analysis of experimental cylinder pressure diagrams.

Another example of the early development of a single zone model for predicting the HRR in diesel engines are single and double Wiebe functions [7]. Since then many authors have used the single and double Wiebe functions in order to predict the average pressure and temperature in DI and IDI engines [8, 9 10, 11, 12].

For non-Wiebe type functions, Whitehouse and Way [4] developed a semi-empirical model for calculating rates of combustion in DI diesel engines which allow calculation of the fuel injection rate and the amount of oxygen available in the cylinder during the combustion process. In their model, the fuel preparation rate for ignition was assumed to be dependent upon the total surface area of the droplets forming the fuel spray. The effect of ignition delay was considered by introducing a chemical reaction rate using an Arrhenius type expression.

Carddock and Hussain [13] developed their single zone model based on experimental data obtained from their single cylinder highly charged diesel engine.

They also divided the combustion process into premixed and diffusion phases. Although their

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correlation looks promising, it has many empirical coefficients which make it difficult to use.

In this work, a new single zone heat release model based on experimental data is developed by looking into the air mass entrained within the fuel spray during the ID. The proposed model assume that combustion process consist of two main phases; premixed and diffusion. The premixed combustion phase is further divided into two stages; accumulation and depletion, Figure 1.

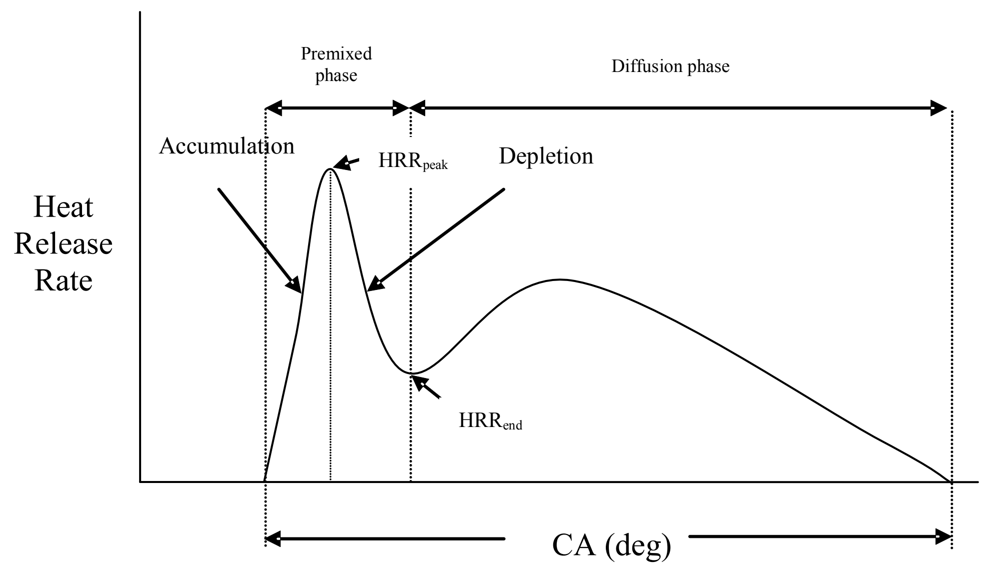

Figure 1 : The two combustion phases and the two premixed combustion stages considered for the new heat release model showing the peak and the end of premixed combustion phase

II. Heat Release Model Development

The development of the new model is based on the assumption that combustion processes will first occur in the air fuel mixture which will define the premixed phase. Before the end of the premixed combustion phase, the flame front will propagate towards the air mass surrounding the premixed phase initiating the diffusion combustion. From experimental data, the end of premixed combustion phase is shown in Figure 2 and is defined by the dotted line.

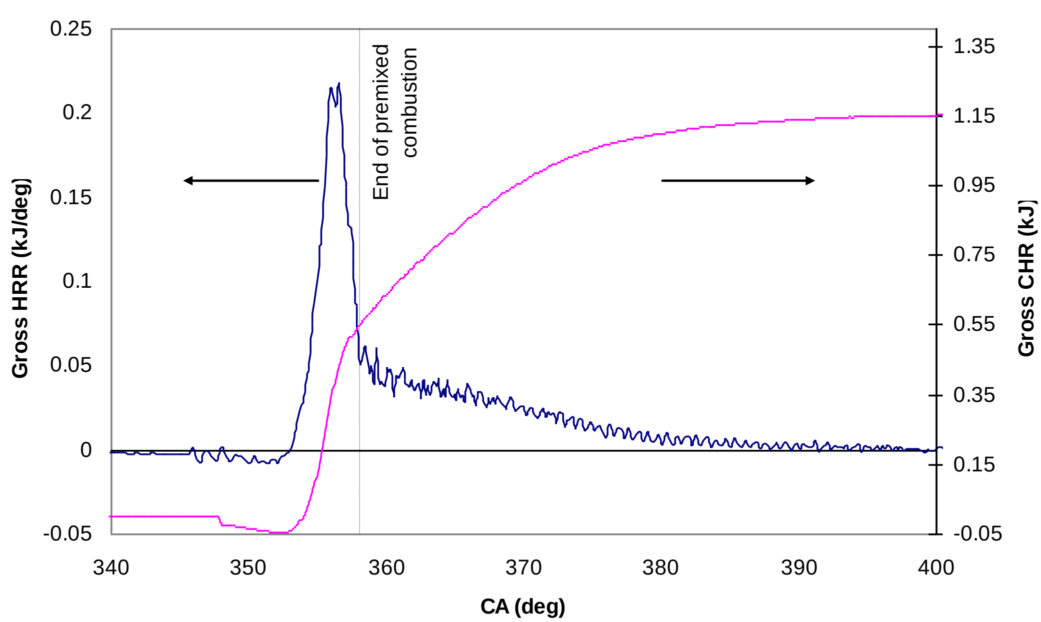

Figure 2 : Gross cumulative and heat release rate at 1200RPM and 150N.m using AD

From the cumulative heat release curve shown above, the energy released at the end of the premixed phase is 0.55 kJ and mass of fuel required to release this energy is 12.9 mg. However, the mass of fuel injected during ignition delay was 18.8 mg. This proves that not all the fuel injected during the ignition delay is burned during the premixed phase. Therefore the fuel mass injected during ignition delay is difficult to rely upon in order to predict the premixed combustion phase.

The prediction of premixed combustion phase for the new heat release model is based on the amount of air entrained during the ID within the air fuel mixture.

Figure 3 shows the plot of the gross HRR from the start of combustion until its peak value (HRRpeak), the calculated air mass entrained within the air fuel mixture from the start of injection (SOI) until the start of combustion (SOC) and the cumulative fuel injected from SOI to SOC.

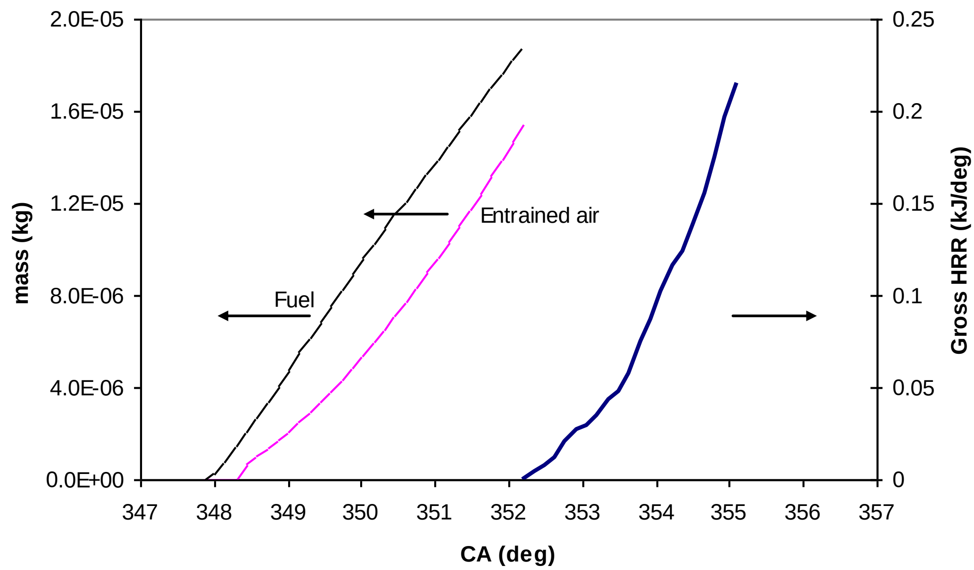

Figure 3 : Calculated air mass within the air fuel mixture formed during ID, cumulative fuel injected during ID and gross HRR from SOC until HRRpeak based on experimental parameters at 1200RPM and 150N.m using AD

The calculation of cumulative air mass entrained within the air fuel mixture is calculated knowing the fuel spray angle and penetration length as follows,

$$m_{air(M)} = \frac{\pi}{3}\tan\left(\frac{\phi_s}{2}\right)^2 \rho_{air}\,(X - X_{brs})^3 . \qquad (1)$$

Where:

ϕ_s is the spray angle

ρ_{air} air density

X Spray penetration length

X_{brs} is the breakup length with swirl effect

The time between SOI and the start of air entrainment is the break up time. Assuming injected fuel is in the vapor phase beyond the break up length, it is clear from Figure 3 that the air fuel mixture at any crank angle is fuel rich during the ignition delay.

The time lag between the air mass entrained and the HRR curves represent the ignition delay period minus the break up time. During this time the mixture is prepared for combustion.

Whitehouse and Way [14] explained this preparation time as the time for fuel to be heated and mix with a sufficient amount of oxygen for stoichiometric burning.

Although there is a similarity between the new heat release model which is about to be developed here and Whitehouse and Way preparation rate, their preparation rate was mainly rely on the amount of fuel prepared during ignition delay time. For the new model fuel is assumed to be always prepared during fuel injection process. Therefore, the entrained air will be used to describe the heat release rate. From the experimental parameters at 1200RPM and 150N.m using AD and by trial and error, fitting an exponent of 1.5 to the air mass entrained and an exponent of 0.1 to the cumulative fuel injected and using the product of air and fuel masses resulted in a correlation with the gross HRR curve during accumulation phase. In other words, the air mass entrained within the air fuel mixture and cumulative fuel injected can be correlated with the gross HRR accumulation phase. This assumes that during the delay between the SOI and SOC, the fuel and air mixes and become ready for combustion, Figure 4.

Global Journal of Researches in Engineering (B) Volume XIV Issue IV Version I Year 2014

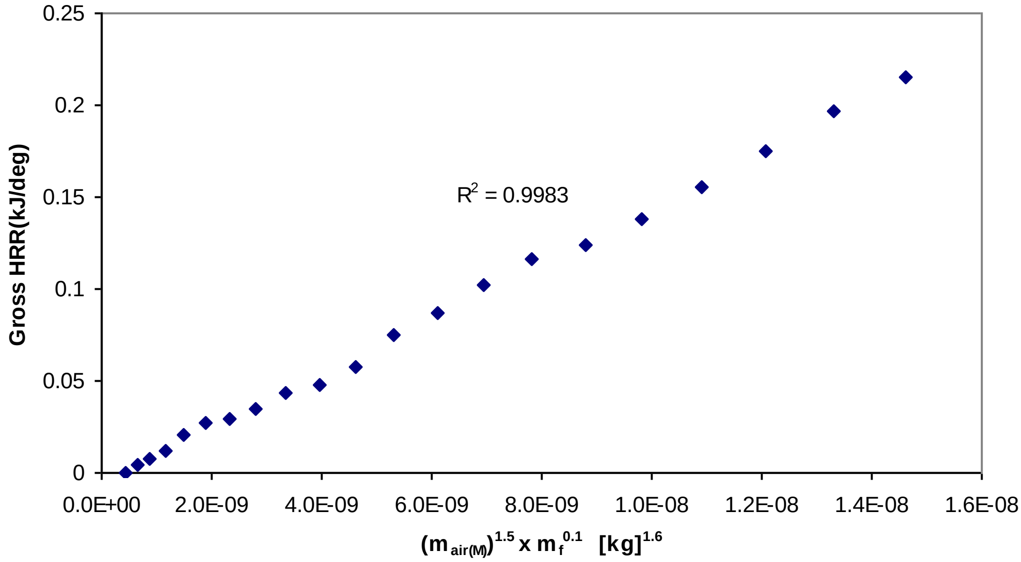

Figure 4 : Gross heat release rate during the accumulation phase versus air mass entrained during the ID to the power 1.5 and cumulative fuel injected during the ID at 1200RPM and 150N.m using AD

This was true for all test points during this study using standard diesel fuel. It is evident that the accumulation phase of the gross HRR is directly proportional to the mass of cumulative fuel injected and the mass of entrained air within the air fuel mixture during the ID. Then the gross HRR relationship becomes,

$$HRR_{prem} \alpha (m_{air(M)}^{1.5}\ m_f^{\ 0.1}) . \qquad (2)$$

Replacing the proportionality with a constant, then equation (2) becomes,

$$HRR_{prem} = K_{prem}\ m_{air(M)}^{1.5}\ m_f^{\ 0.1} . \quad \text{(kJ/deg)} \qquad (3)$$

Where K_{prem} (kJ kg$^{-1.6}$ deg^{-1}) is an adjustable constant. By superimposing the air mass entrained curve over the HRR_{prem}, the gross HRR during the accumulation phase can be calculated using equation (3). The air mass can be calculated from equation (1) from the SOI until the SOC. Also the fuel mass is calculated from the SOI until the SOC. Once the maximum value of the air mass entrained during ID is reached (at SOC), the heat release rate peak is assumed to be reached. If combustion process is assumed to take place at stoichiometric conditions, the remaining air mass entrained within the air fuel mixture will then be subtracted from the burned air during each time step which will define the depletion phase as shown in the following equation,

$$m_{air(M)i} = m_{air(M)i-1} - m_{air(burned)} \qquad (4)$$

Where $m_{air(M)i}$ is the unburned air mass entrained at present step and $m_{air(M)i-1}$ is at the previous step. The unburned fuel can be calculated similarly as the unburned air mass,

$$m_{f(i)} = m_{f(i-1)} - m_{f(burned)} + m_{finj(step)} \qquad (5)$$

Where $m_{f(i)}$ is the mass of unburned fuel at present step and $m_{f(i-1)}$ is at the previous step. $m_{finj(step)}$ the mass of fuel injected during the time step. Equations (4) and (5) define the depletion stage during the premixed combustion phase (Figure 1). Once the fuel injection process ends, $m_{finj(step)}$ becomes zero. Figure 5 shows an illustration of the corresponding air and fuel masses accumulation and depletion trends during the premixed combustion phase.

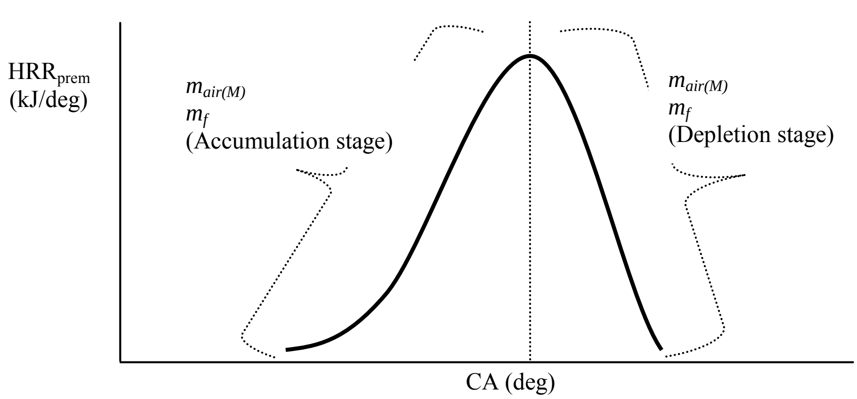

Figure 5 : The premixed combustion phase at the start of accumulation until the end depletion stages

The method used in developing the gross HRR during the premixed combustion phase is also followed for the diffusion combustion phase. The gross HRR from experimental data during the diffusion phase is plotted in Figure 6.

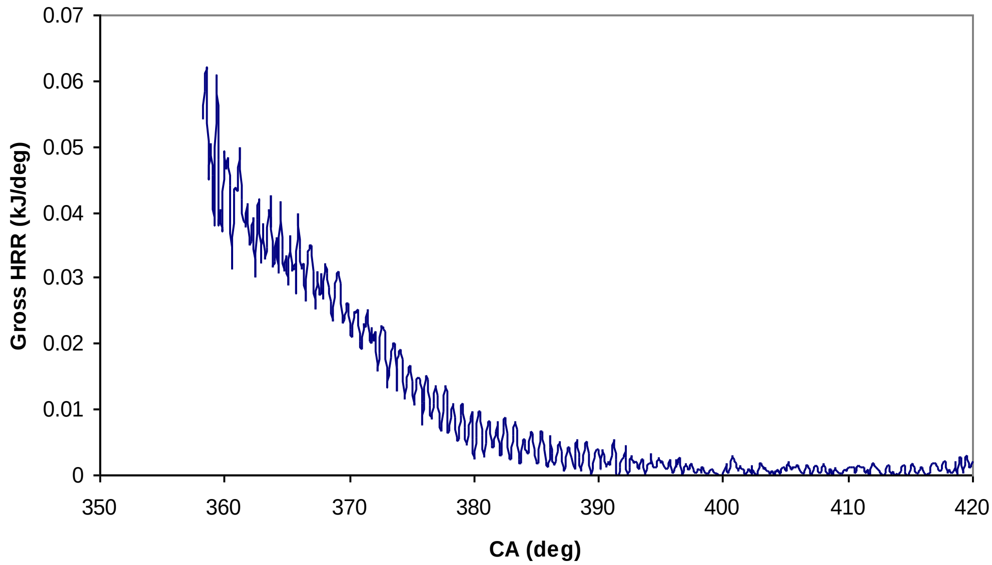

Figure 6 : The gross HRR during the diffusion phase at 1200RPM and 150N.m using AD

During the diffusion phase, the calculated unburned air mass within the cylinder from the experimental parameters is shown in Figure 7.

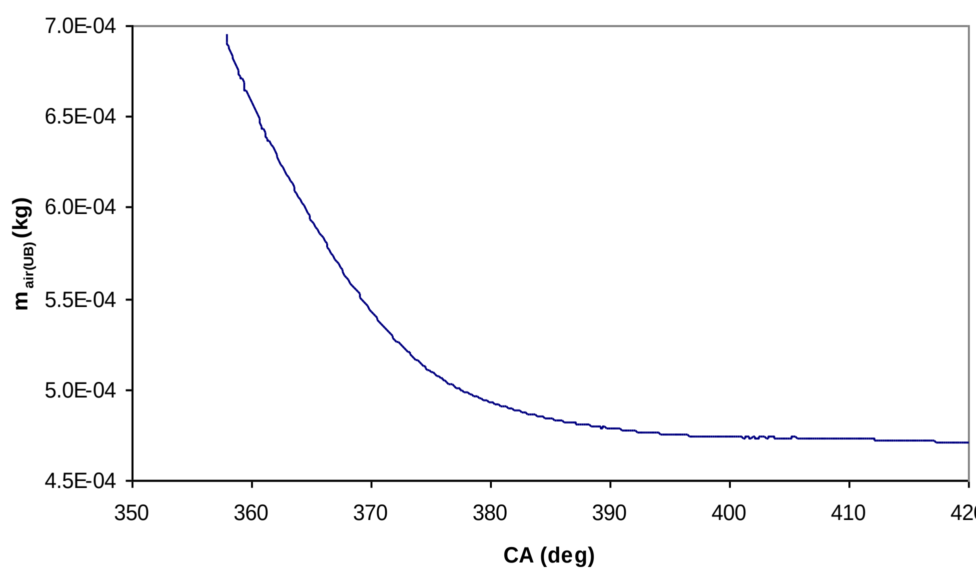

Figure 7 : The calculated unburned air mass from experimental parameters at 1200RPM and 150N.m using AD

Using an exponent of 0.5 for the unburned fuel, the unburned air and fuel masses can then be correlated with the HRR during the diffusion phase, Figure 8.

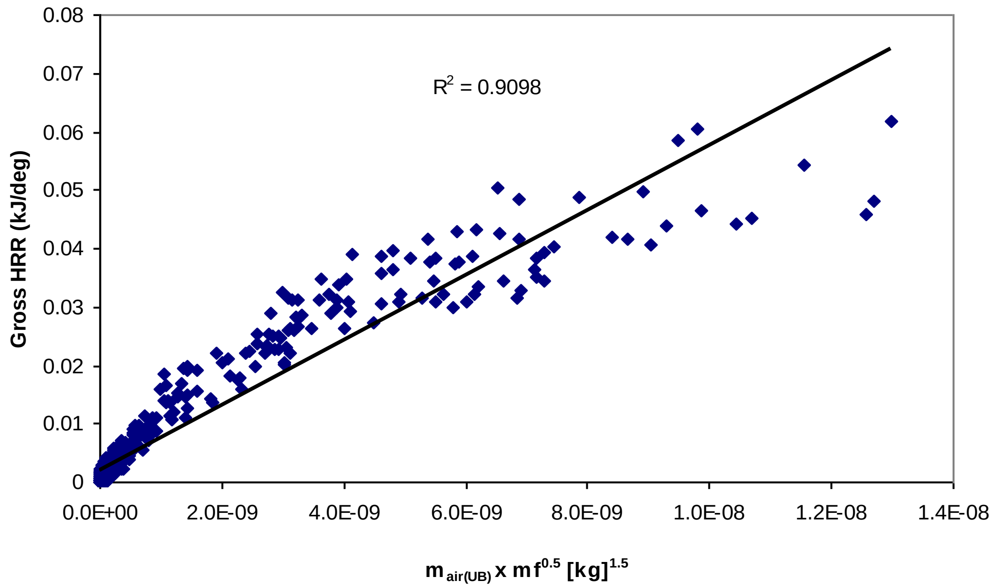

Figure 8 : The gross HRR during diffusion stage versus unburned air and fuel masses at 1200RPM and 150N.m using AD

Each data point in the above Figure represents the experimental gross HRR against the calculated air and fuel masses from the start of diffusion phase until it ends. The curve fit used for the diffusion phase for all test points is from the starting point of diffusion phase which is defined by the end of premixed combustion (Figure 2) until the end of combustion process. Since the fuel mass will define the end point of the diffusion combustion phase, the unburned fuel mass which did not react during the premixed combustion will be used in the diffusion combustion correlation. From the experimental data, the trend for the unburned fuel is similar to the mass of unburned air, Figure 9.

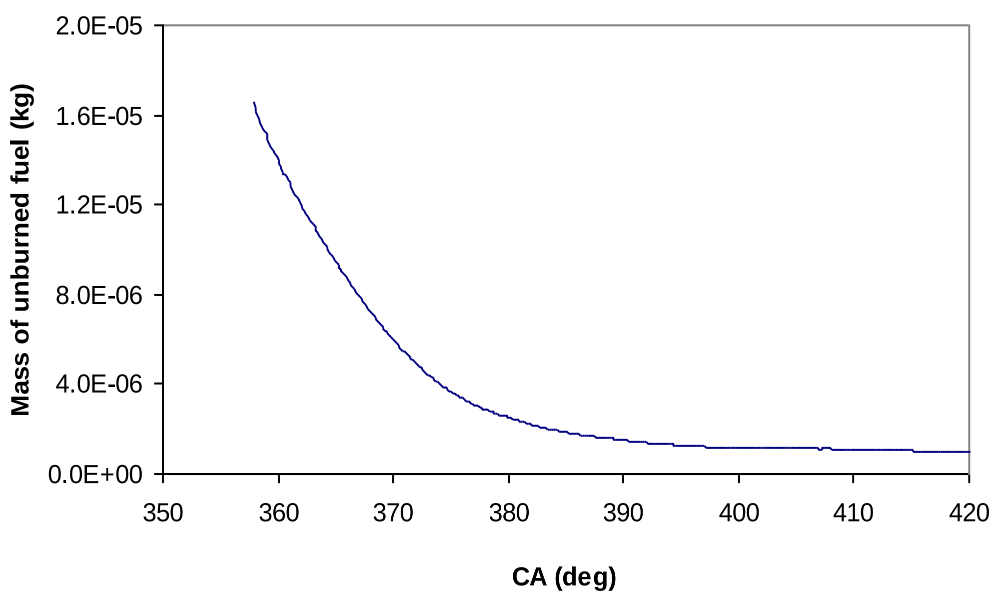

Figure 9 : The mass of unburned fuel during the diffusion phase at 1200RPM and 150N.m using AD

As it was the case with the premixed phase, the gross HRR during the diffusion combustion phase is directly proportional to the unburned air and fuel masses,

Global Journal of Researches in Engineering (B) Volume XIV Issue IV Version I Year 2014

$$HRR_{diff}\,\alpha(m_{air(UB)}\ m_f^{\ 0.5})\,. \qquad (6)$$

Replacing the proportionality term with a constant, the final form of the heat release rate during diffusion phase is,

$$HRR_{diff} = K_{diff}\ m_{air(UB)}\ m_f^{\ 0.5}.\ \ \text{(kJ/deg)} \qquad (7)$$

Where K_{diff} (kJ kg$^{-1.5}$ deg^{-1}) is an adjustable constant for the diffusion phase. In this case, equations (4) and (5) are to be used in equation (7) from the beginning until the end of the diffusion combustion. In equation (4), the remaining unburned air mass is used instead of the air mass within the air fuel mixture. At the beginning of the combustion cycle, the premixed HRR takes place first. Once the diffusion HRR is greater than the premixed HRR, the process is assumed to continue as a diffusion process until all fuel is completely burned,

$$HRR_{cycle} = \text{Max}\ (HRR_{prem},\ HRR_{diff}).\ \ \text{(kJ/deg)} \qquad (8)$$

Figure 10 shows the outcome of the HRR for the premixed phase (equation 3) and the diffusion phase (equation 8) shown above.

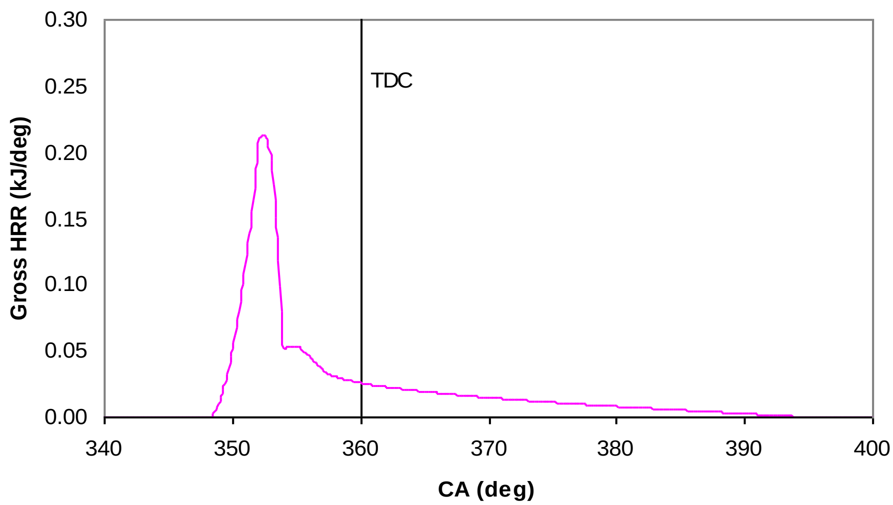

Figure 10 : Predicted gross HRR at 1200RPM and 150N.m using AD

From the SOC, the premixed phase dominates the combustion process. Once the HRR_{peak} isreached the diffusion phase starts to buildup while the premixed starts to deplete. Once thediffusion HRR becomes higher than the premixed, it dominates the combustion process until the end of the process. The constant K_{prem} is adjusted in order to match the peak HRR of the model to that of experimental data while K_{diff} is adjusted to have the best fit between the model and experimental diffusion curves. For this test point, K_{prem} and K_{diff} are 1.06E10^7 (kJ kg^{-1}.6 deg^{-1}) and *1.40E10^4* (kJ kg^{-1}.5 deg^{-1}) respectively.

III. Experimental Setup

Experimental tests were conducted on four cylinders, 4.009L, Hino direct injection naturally aspirated medium speed diesel engine. The fuel injection system utilizes a BOSCH A-type in-line fuel pump and hole type injector nozzle. The engine was attached to an eddy-current dynamometer through an 80cm telescopic shaft. The dynamometer has a maximum power of 150 brake horsepower and maintains load on the engine by dissipating its mechanical power produced. The dynamometer controller is a Schenck electronic type which keeps the engine at a constant desired speed by varying the supply current to the dynamometer. The overall experimental setup is shown in Figure 11 while engine and injector specifications are listed in table 1.

Comparison between real and model heat release curves

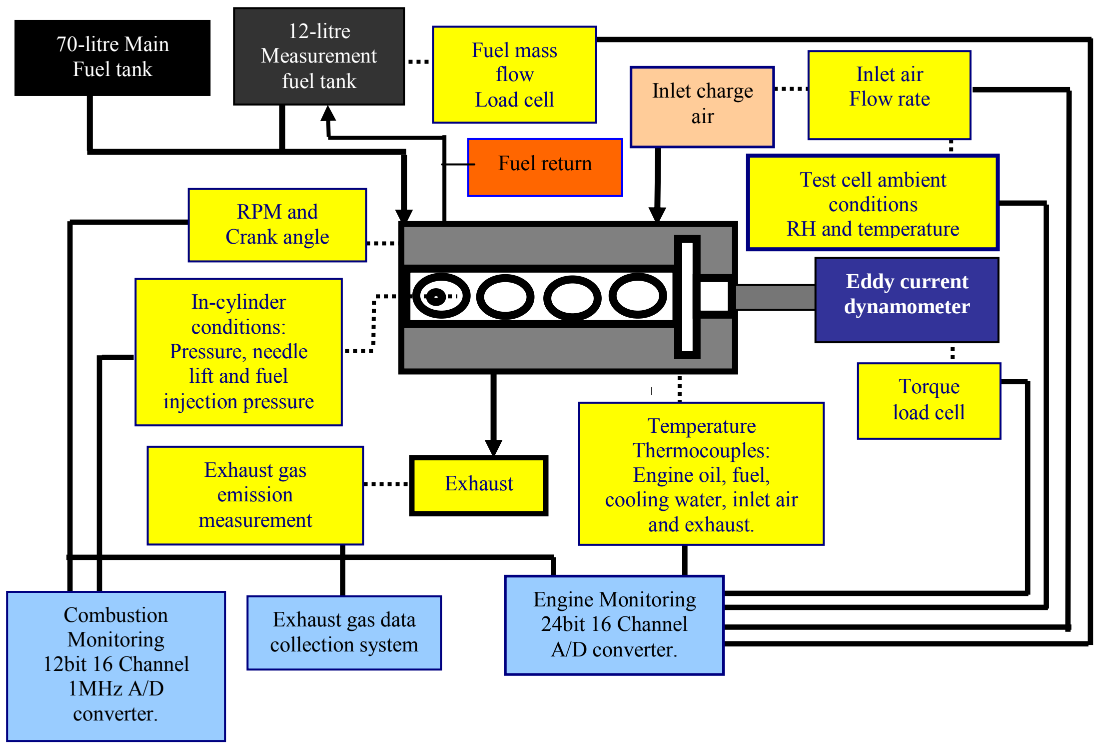

Figure 11 : Experimental Setup

Table 1 : Test engine specifications

Bore (B) x Stroke (l)	104 x 118(mm)
Compression Ratio (r)	17.9
Connecting rod length (L)	181.75 (mm)
Injector Nozzle (D_n)	5 holes x 0.29 mm dia x 160 deg cone angle
Needle opening pressure	215BAR
Valve timing	IVO (8^0 BTDC) – IVC (48^0 ABDC) EVO (60^0 BBDC) – EVC (8^0 ATDC)
Fuel pump plunger	9.5 mm dia x 8 mm max. stroke
Piston bowl shape	Toroidal

Three data acquisition systems were used to gather and record engine data. The engine performance data acquisition 24 bit, 1HZ National Instruments system was used to monitor and record engine load, air and fuel flow rates (turbine flow meter), relative humidity, and engine exhaust, fuel, inlet air, engine oil and coolant temperatures. The intake manifold was instrumented with an absolute pressure transducer with 0-1.6BAR range and 0-5v output and a K-type thermocouple. The fuel flow mass was gravimetrically measured using a 20kg “S” beam load cell (model LC-1205-K020) loaded in tension which can take up to 20kg of fuel mass. Knowing the air and fuel flow rates it is possible to determine the overall equivalence ratio for any test point. Humidity was measured using a capacitive humidity sensor (model EE06-A) with 0-100% range and 0-1V output. A thermocouple was placed in the exhaust manifold near the exhaust valve to measure the exhaust temperature and to compare later with the model temperature at the end of the expansion stroke. Another thermocouple was also used to measure engine coolant temperature and was used as a reference to determine when the engine reaches a steady state condition. All the thermocouples used were of K-type.

The second data acquisition system was used to monitor and record cylinder pressure, needle lift and fuel injection pressure readings at each crank angle position. An AVL piezoelectric high-pressure transducer (model GU12P) was mounted in the unused glow plug of cylinder number one for recording cylinder pressure. The fuel pressure was measured using an AVL fuel line high-pressure transducer (model SL31D-2000) mounted 50mm away from the injector in order to minimize fuel pulsations in the fuel pressure data. A third AVL sensor was used for monitoring the needle lift. The output of the transducers and the needle lift sensor were all fed to charge amplifiers, which convert the charge output to a voltage.

This voltage was fed to a data acquisition board capable of simultaneous sampling multi channels at 233kbps rate. This data acquisition board communicates with a personal computer through the parallel port. The crank angle position was measured using an optical encoder mounted on the front pulley of the crankshaft. The encoder has two-channels; one channel provides a pulse at top dead center while the other gives a pulse every 0.1deg of crank angle. The second data acquisition system output signals were all fed into an AVL Indimeter 619, which was used for continuous engine monitoring. The Indimeter 619 output signal was acquired using a PC with AVL Indicom software, which records and visualizes the in-cylinder data at each pulse. This gives 7200 data points for each cycle.

The third acquisition system used was a CODA exhaust gas analyzer. It measures and records NO_x (ppm), CO (%), CO_2 (%), HC (ppm) and O_2 (%) by means of chemiluminescence and electro-chemical cells. The CODA analyzer was also capable of reading lambda (air fuel ratio) based on the CO_2 and O2 exhaust measurements. Exhaust emissions especially NO_x readings were used to determine when the engine reaches steady state condition since they are more sensitive to the stability of combustion temperature.

IV. Model Validation

For a baseline test, the authors operated the engine at six speeds with two loads for each engine speed using standard diesel fuel as shown in table 2.

Table 2 : Speeds and loads considered in this work

Engine speed (RPM)	Load (N.m)	
1200	150	200
1400	150	200
1600	150	200
1800	150	200
2000	150	200
2200	150	200

Each test point data represents an ensemble average of three sample points for the engine performance data per indicated value whereas the in-cylinder measurements represent an ensemble average of 10 cycles. The model was first verified against experimental work using standard diesel fuel. The heat release model adjustable constants and swirl ratio are set at their optimum values in order to have the best match between experimental and predicted cylinder pressure and heat release data. The reason of doing this is to correlate the premixed and diffusion adjustable constants to the engine operating conditions. The HRR from the new model has shown to be in a good agreement with the experimental data as it is expected since adjustable constants were adjusted to match the experimental data.

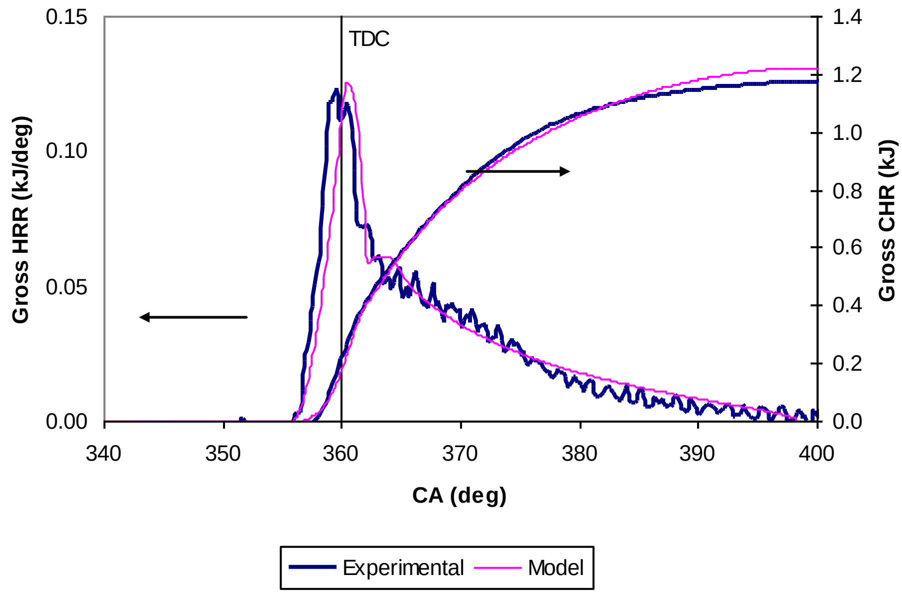

Figure 12 : Experimental and predicted cumulative and rate heat release using optimum premixed and diffusion constants at 1800RPM and 150N.m

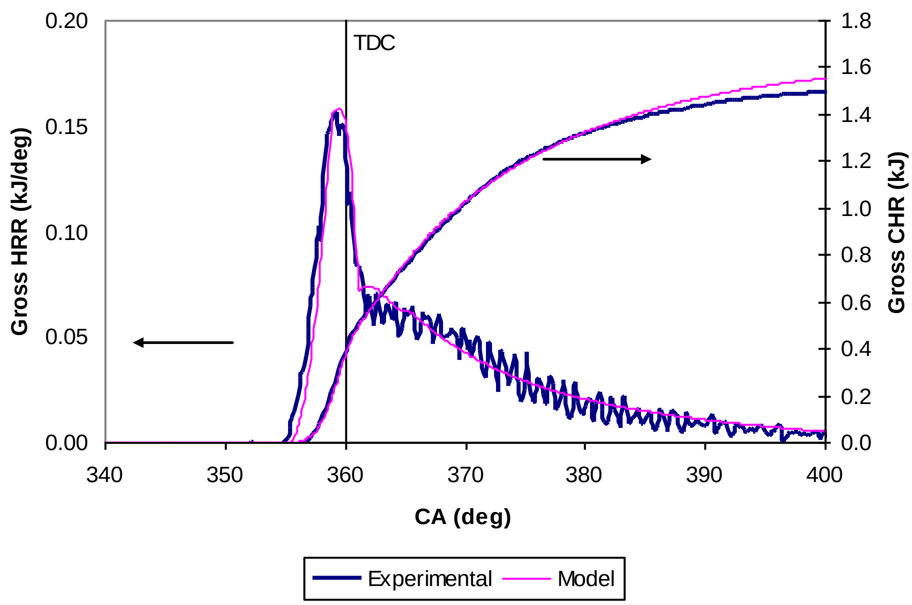

Figure 13 : Experimental and predicted cumulative and rate heat release using optimum premixed and diffusion constants at 1800RPM and 200N.m

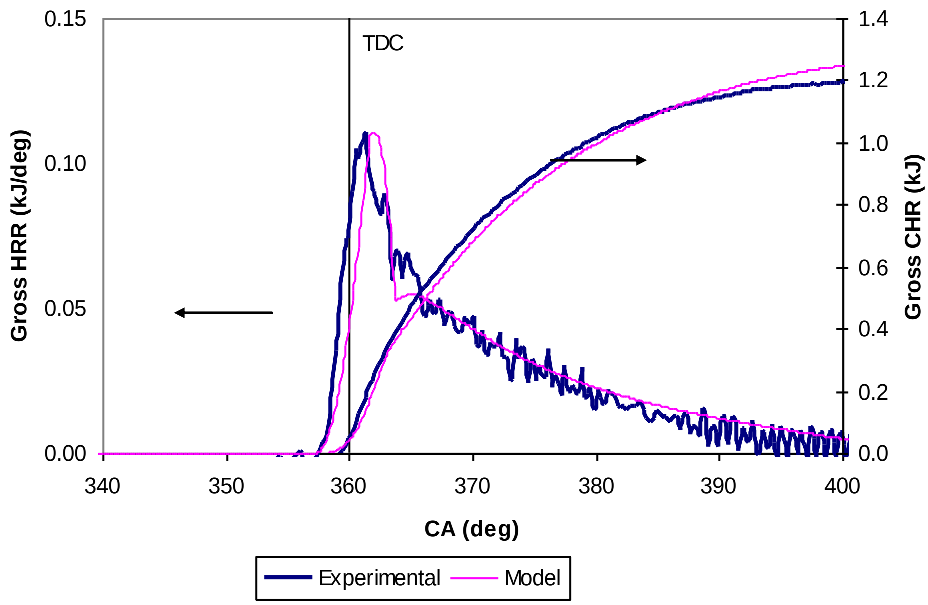

Figure 14 : Experimental and predicted cumulative and rate heat release using optimum premixed and diffusion constants at 2200RPM and 150N.m

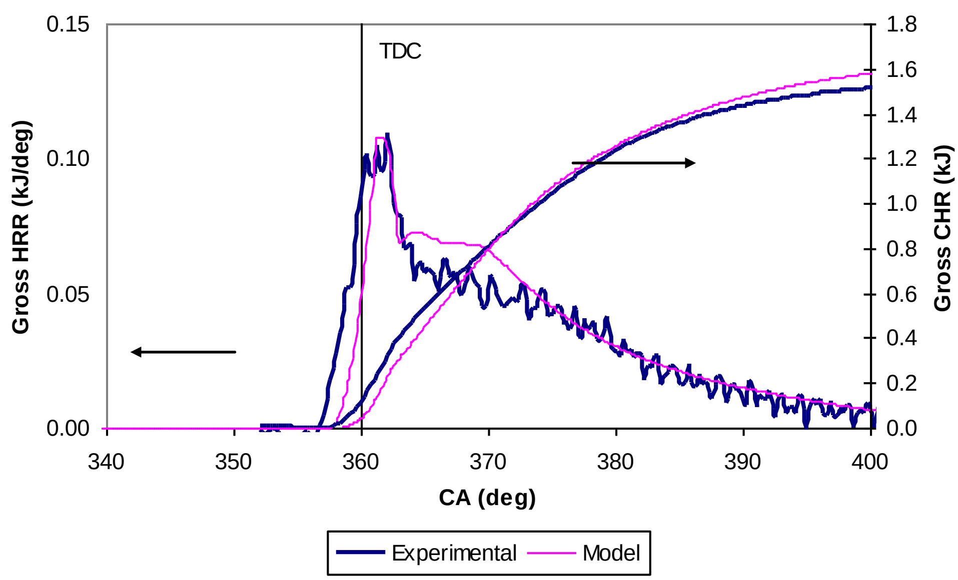

Figure 15 : Experimental and predicted cumulative and rate heat release using optimum premixed and diffusion constants at 2200RPM and 200N.m

The offset between the predicted and experimental HRR data is due to the difference between the experimental and correlated ID. The duration of the predicted premixed combustion phase agrees well with that of the experimental data especially at lower engine load. At 200N.m load, the predicted duration of the premixed combustion phase is shorter than that of the experimental data. The model adjustable constants and swirl ratio at their optimum values used for the above cases are shown in table 3.

Table 4 : Optimum heat release model constants for the above cases

RPM	Load	Kprem.	Kdiff.	Swirl ratio
1800	150	7.01E+06	1.70E+04	9.0
	200	5.74E+06	2.12E+04	5.0
2200	150	6.16E+06	1.62E+04	6.0
	200	5.53E+06	2.12E+04	5.0

V. Heat Release Model Calibration

In the previous section, the heat release adjustable constants in the model were set at their optimum values for each case to obtain the best fit between the experimental and predicted cylinder pressure and heat release rate curves. At this point it is worthwhile to investigate the correlation between these constants in the model and engine operating conditions. From the modelling results, it was noted that the premixed adjustable constant Kprem at their optimum values is dependent on the average difference between the fuel injection pressure and cylinder pressure. This finding motivated an attempt to correlate one against the other, Figure 16.

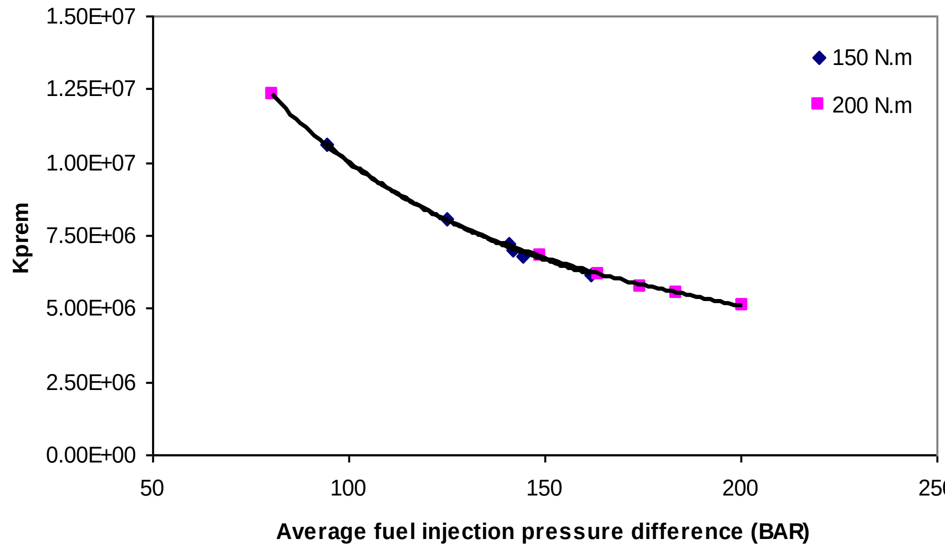

Figure 16 : The dependence of optimum Kprem on average fuel injection pressure difference for the two loads and all engine speeds

The two fitted lines have similar trends and slopes. For the 200N.m, K_{prem} values have bigger variation throughout the range of engine speeds and marginally higher than that of 150N.m. The data points at 150N.m are more clustered than at 200N.m. The average fuel injection pressure difference was found while holding the nozzle discharge coefficient at *0.70.* Taking the average of the above two curves gives an estimation of K_{prem}, Figure 17.

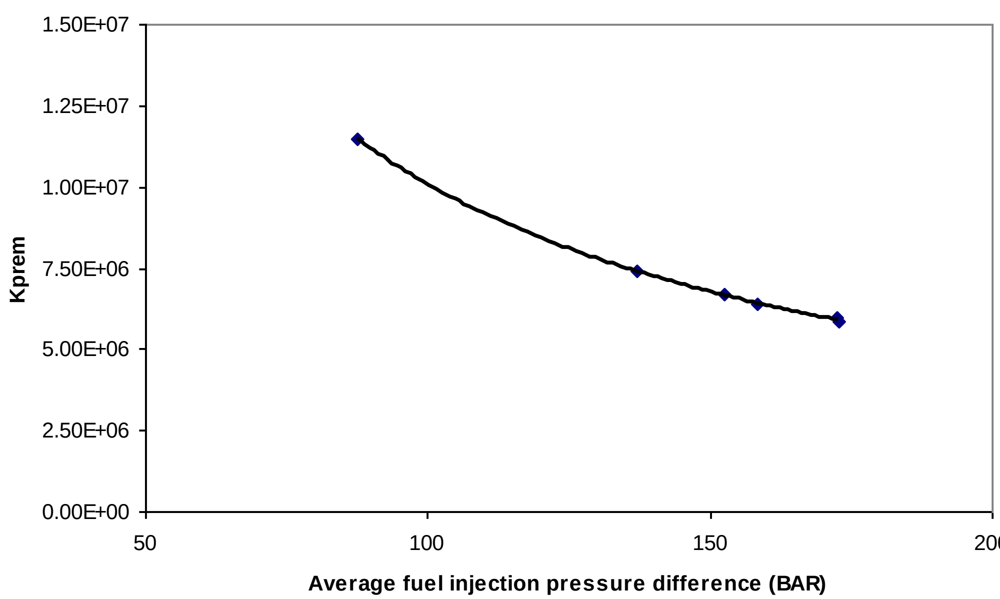

Figure 17 : Average values of K_{prem} and fuel injection pressure difference at all engine speeds and both loads

Global Journal of Researches in Engineering (B) Volume XIV Issue IV Version I Year 2014

Using a power line fit to the data of Figure 17, the premixed adjustable constant can now be calculated using the following general correlation,

$$K_{prem} = 1.0 \times 10^{9} \ \Delta P^{-1.0} \qquad (9)$$

Where ΔP P is the calculated average fuel injection pressure difference (BAR). The above correlation can now be used to recalculate K_{prem} as shown in table 5.

Table 5 : The calculated premixed adjustable constant for the fitting cases

RPM	Load	Kprem	
		Optimum values	Calculated values
1800	150	7.01E+06	7.05E+06
	200	5.74E+06	5.73E+06
2200	150	6.16E+06	6.18E+06
	200	5.53E+06	5.45E+06

For the above cases the variation range between the optimum and calculated values of K_{prem} is less than 3%. Other test points also showed good agreement between the optimum and calculated premixed adjustable constant (within 3% variation).

Similarly plotting the diffusion adjustable constant Kdiff at their optimum values at all engine speeds and both loads using AD is shown in Figure 18.

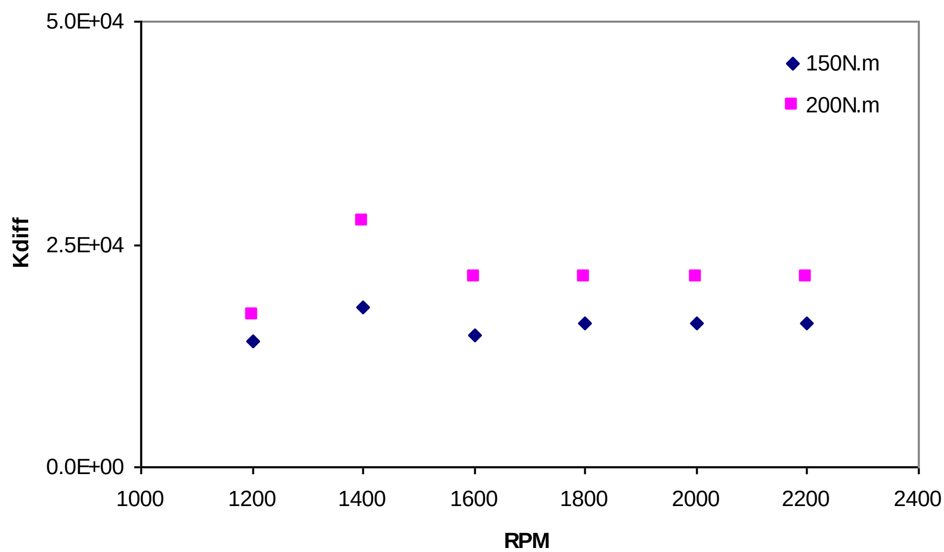

Figure 18 : The optimum diffusion adjustable constant values at all engine speeds and both loads

The trends of both loads are almost constant throughout the whole engine speed range while higher load has higher K_{diff} values. For the diffusion adjustable constant, no specific trend could be found with the fuel injection pressure difference as it was the case with K_{prem}. Therefore, an average value of K_{diff} is used in this case. At 150N. m the average K_{diff} is 1.59 E+4 while at 200N.m it is 2.16E+4. The overall average for both loads is 1.87E+4. The maximum variation between the overall average and the optimum diffusion adjustable constant is 18% which occurs at 150N.m. Figures 19 and 20 shows the effect of the variation with the averaging technique on HRR and cylinder pressure curves during the diffusion phase.

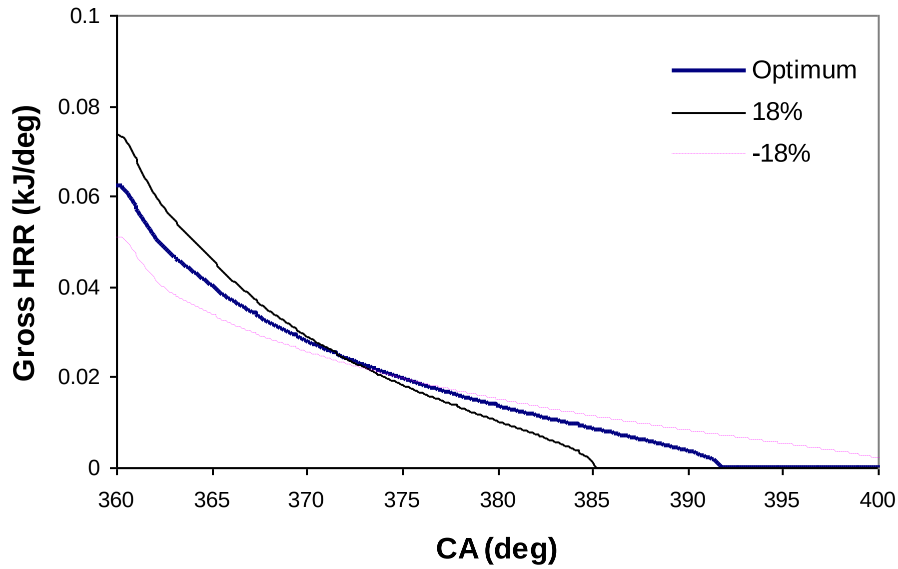

Figure 19 : The gross HRR during the diffusion phase with +/- 18% variation between the optimum adjustable diffusion constant and the overall average constant at 1800RPM and 150N.m

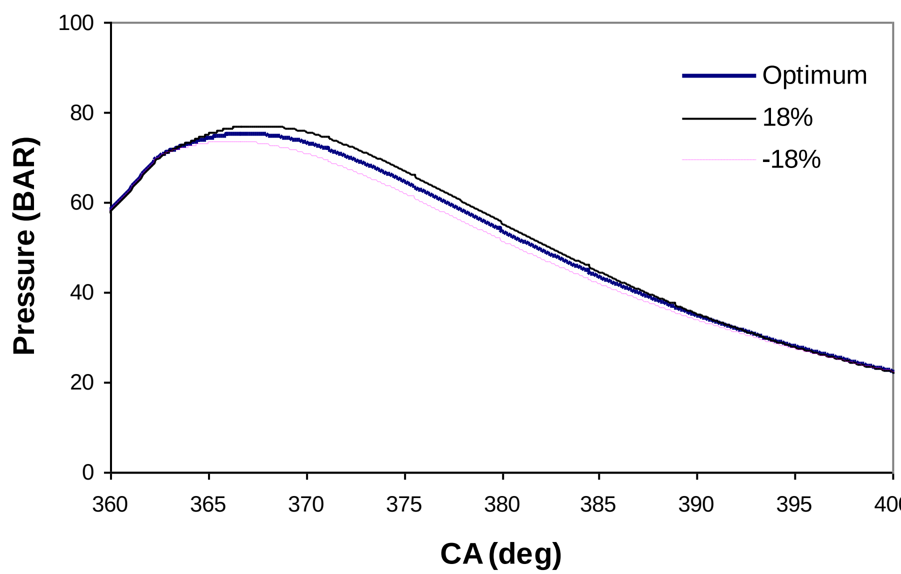

Figure 20 : Cylinder pressure curves with +/- 18% variation between the optimum adjustable diffusion constant and the overall average constant at 1800RPM and 150N.m

The 18% variation in the diffusion phase resulted in 2.6% variation in the cylinder pressure values. In this case the overall average of the diffusion adjustable constant can be used with the expectation of small variation in cylinder pressure readings. Other test points showed better agreement between predicted and experimental pressure and temperatures curves.

VI. Conclusion

A simple method for a single heat release model based on experimental heat release and fuel injection pressure data has been developed. The model uses an Arrhenius based expression to evaluate the rate of premixed and diffusion phases. The premixed phase has been breakup into accumulation and depletion phases using the fuel and air masses mixed and prepared during the ID. The diffusion phase has been developed using the unburned fuel and air. Fuel injection pressure was then used to predict the constants in the newly developed heat release model. The model has successfully predicted the heat release rate hence cylinder pressure and temperature with acceptable margin of error. The model developed offers a stable and accurate platform to calculate the HRR for diesel engine under various operating conditions using standard diesel fuel.

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Global Journal of Researches in Engineering: B
Automotive Engineering
Volume 14 Issue 4 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Aircraft Design and Weight Estimation Nomenclature

By Jahnavi & Avinash

Abstract- Weight components of airplane explained as follows:

a) Crew weight (W_c)

The crew comprises the people necessary to operate the airplane in flight. e.g., Pilot, Co-pilot, Airhostess etc.

b) Payload weight (W_p)

The payload is what the airplane is mentioned to transport passengers, baggage, freight etc. (Military use the payload includes bombs, rockets and other disposable ordnance) .

c) Fuel weight (W_f)

This is the weight of the fuel in the fuel tanks. Since fuel is consumed during the course of flight. is a variable, decreasing with time during the flight.

d) Empty weight (W_e)

This is weight of everything else-the structure engines (with all accessory equipment), electronic equipment landing gear, fixed equipment and anything else that is not crew, payload or fuel.

e) Gross weight (W_0)

The sum of these weights is the total weight of the airplane. Gross weight or total weight varies through the flight because fuel is being consumed. The design take off gross weight is the weight of the airplane at the instant it begins its mission. It includes the weight of the fuel.

GJRE-B Classification : FOR Code: 090101

AIRCRAFTDESIGNANDWEIGHTESTIMATIONNOMENCLATURE

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$$W_0 = W_c + W_p + W_f + W_e$$

$$W_0 = W_c + W_p + \frac{W_f}{W_0} W_0 + \frac{W_e}{W_0} W$$

$$W_0 = \frac{(W_c + W_p)}{\left(1 - \frac{W_f}{W_0} - \frac{W_e}{W_0}\right)} \qquad (1)$$

i. *Estimation of empty weight fraction* (W_e/W_0)

The empty weight fraction (W_e/W_0) can be estimated from data based on

- Historical data and tables
- Refined sizing data and tables

ii. *Estimation of fuel fraction* (W_f/W_0)

The aircrafts fuel supply is available for performing the mission. The other fuel includes reserve fuel, trapped fuel (which is the fuel which cannot be pumped out of the tanks).

Fuel fraction (W_f/W_0) is approximately independently of aircraft weight. Fuel fraction will be estimated based on the mission to be flown.

I. Introduction

a) Mission profiles

Typical mission profiles for various types of aircraft are shown in Fig1. The simple cruise mission is used for many transport and general aviation designs, including home built. Following are the briefly explained the terms that are used in mission profiles:

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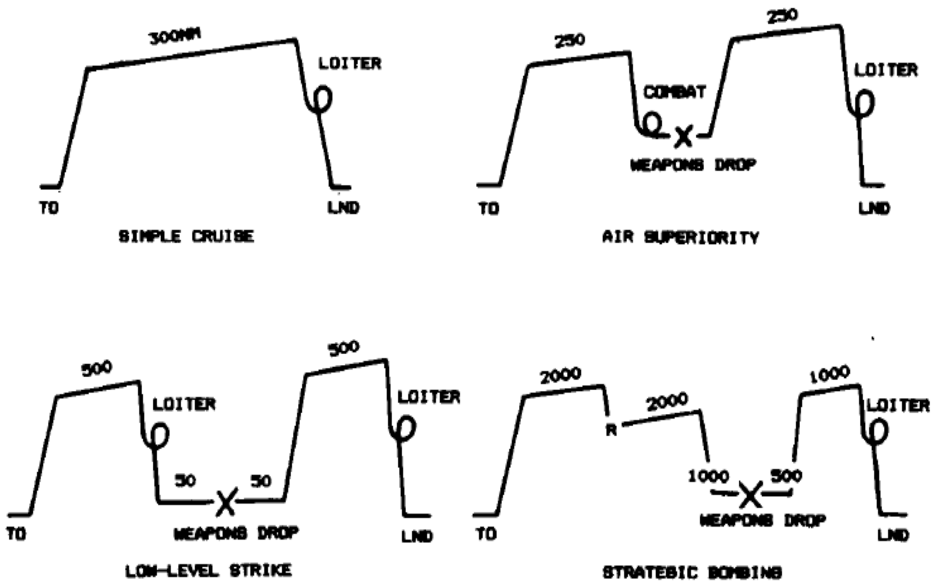


Fig.1 : Typeical mission profiles for sizing

- *Warm Up and Take-Off*

Warm Up is the engine start up for the airplane kept idling for some time to warm up. Take Off is the point where aircraft is made lift off from ground. It is the motion after warm up i.e., moving of airplane after starting and till it lifts off from the ground.

- *Climb*

It is between take-off (TO) and cruise (stead level flight with constant speed) Increase in height until airplane achieves steady level flight.

Cruise

It is the steady level flight to cover the mission distance. The mission distance is called Range.

- *Loiter*

Represent the airplane spending in air for some fixed number of minutes near airport before getting the clearance from airport signal or simple spending some time to collect data of some mission (Terrain data).

- *Dash*

It is the mission that must be flown at just a few hundred numbers of feet of the ground for low level strike.

- *Landing*

It is the aircraft landing on the runway till stopping of engine.

b) Estimation of mission segment weight fractions

The various mission segments (legs) are numbered starting from zero denoting, the start of the mission. Mission leg one is usually engine warm up and take-off. The remaining legs are sequentially numbered. For example in the simple cruise mission the legs could be numbered as (0) warm-up and take-off, (1) climb (2) cruise (3) loiter and (4) landing.

Similarly, the aircraft weight at end of each mission is denoted by W_i . Denoting "i"-th segment as mission segment weight

W_0 =Beginning airplane weight ("Take –off gross weight")

W_1 =Weight of the airplane at end of warm-up and take-off.

W_2 =Weight of the airplane at end of climb.

W_3 =Weight of the airplane at end of cruise.

W_4 =Weight of the airplane at end of loiter.

W_5 =Weight of the airplane at end of landing.

$$W_x/W_0 = \frac{W_5}{W_0} = \frac{W_1}{W_0}\frac{W_2}{W_1}\frac{W_3}{W_2}\frac{W_4}{W_3}\cdots\frac{W_5}{W_4}$$

So in general it can be written as

$$W_x/W_0 = \frac{W_i}{W_0} = \frac{W_1}{W_0}\frac{W_2}{W_1}\frac{W_3}{W_2}\frac{W_4}{W_3}\cdots\frac{W_i}{W_{i-1}}$$

Warm-up/take-off, climb and landing weight fractions:

The warm-up, take-off and landing weight fractions can be estimated historically from Table 2.

Table 2 : Historical mission segment weight fractions

	(W_i/W_{i-1})
Warmup and takeoff	0.970
Climb	0.985
Landing	0.995

Specific fuel consumption (C)

It is the rate of fuel consumption divided by the resulting thrust. Typical values are depicted in Table3 and Table4 for jet and propeller aircrafts respectively. If the aircraft is propeller, then C should be replaced by

$$C = C_{bhp}V/(550\eta_p)$$

Table 3 : Specific fuel consumption (C)

Typical jet SFC's	Cruise	Loiter
Pure turbojet	0.9	0.8
Low-bypass turbofan	0.8	0.7
High-bypass turbofan	0.5	0.4

Table 4 : Propeller specific fuel consumption (C_{bhp})

Propeller: $C = C_{bhp}V/(550\eta_p)$ Typical C_{bhp} and η_p	Cruise	Loiter
Piston-prop (fixed pitch)	0.4/0.8	0.5/0.7
Piston-prop (variable pitch)	0.4/0.8	0.5/0.8
Turboprop	0.5/0.8	0.6/0.8

Cruise segment weight fraction

Weight fraction for cruise segment is found using Breguet range formula

$$R = \frac{V}{C}\frac{L}{D}\ln\left(\frac{W_{i-1}}{W_i}\right)$$ R = range, C = specific fuel consumption

$$\frac{W_i}{W_{i-1}} = \exp\left(\frac{-RC}{V\left(L/D\right)}\right)$$ V = velocity, L/D = lift to drag ratio

Loiter segment weight fraction

Weight fraction for loiter segment is found using Endurance formula.

$$E = \frac{L/D}{C}\ln\left(\frac{W_{i-1}}{W_i}\right)$$ E = endurance or loiter time, C = specific fuel consumption

$$\frac{W_i}{W_{i-1}} = \exp\left(\frac{-EC}{(L/D)}\right)$$ V = velocity, L/D = lift to drag ratio

The most efficient cruise is velocity for propeller aircraft occurs at velocity yielding max L/D, where as for the most efficient cruise for a jet aircraft occurs at slightly at a higher velocity yielding an L/D of 86.6% of the maximum L/D

Type of aircraft	Cruise	Loiter
jet	0.866 (L/D)max	L/D max
propeller	L/D max	0.866 (L/D) max

For any mission segment "i" the mission segment weight fraction is expressed as W_i/W_{i-1}. W_x (Assuming "x" segments are present for total mission profile) is the aircraft weight at end of the mission. W_x/W_0 ratio can be used to calculate fuel fraction.

$$W_f/W_0 = 1-(W_x/W_0)$$

At the end of the mission, the fuel tanks are not completed empty, typically a 6% allowance is made for reserve and trapped fuel

$$W_f/W_0 = 1.06[1-(W_x/W_0)]$$

c) Estimate of gross weight at take-off (W_0)

W_e/W_0 is function of W_0, W_f/W_0 is also a function of W_0. W_0 is calculated from equation(1) through process of iteration. W_0 is taken a guess value and, then RHS value of equation(1) is calculated which should match the value of assumed, if it doesn't, increment the assume by some value and iterate it. This process is continued till the absolute difference of RHS value and assumed value is the least and that iteration step will be your nearest solution.

II. Aircraft Conceptual Sketch and Its Gross Weight Estimation Algorithm Aim

Write the request for proposal for the particular aircraft, draw the conceptual sketch of the aircraft for given type of aircraft, draw the mission profile and write generic algorithm for gross take-off weight estimation

Theory

a) Conceptual Design

Conceptual design begins with a specific set of design requirements established from customer or a company-generated guess what future customers may need.

Design requirements include

- Aircraft range
- Payload
- Take-off distance
- Landing distance
- Maneuverability and speed requirements

Design begins with innovative idea rather than as a response to a given requirement. Before design a decision is made to what technologies to incorporate, it must use only currently available technologies as well as existing engines and avionics. If designed to build in more distant future, then an estimate technological state of the art must be made to determine which emerging technologies will be ready for use at that time.

Design begins drawing with a conceptual sketch like shown in Fig1. Good conceptual sketches start with approximate sketch of following:

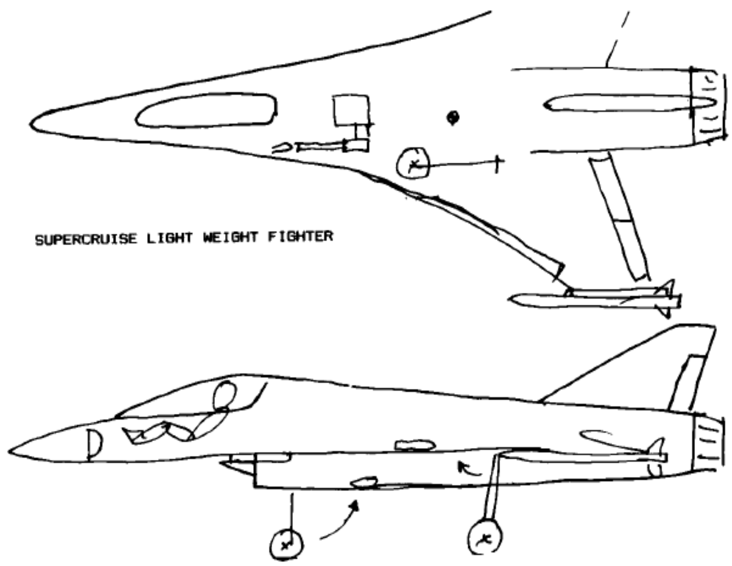


Fig.1 : Initial sketch

1) Wing
2) Tail geometries
3) The fuselage shape
4) The internal locations of the major components such as the:
   a) Engine
   b) Cockpit
   c) Payload/passenger compartment
   d) Landing gear
   e) Fuel tanks.

III. Sizing

The conceptual sketch is used to estimate aerodynamics and weight fractions by comparisons to previous designs. These estimates are used to make a first estimate of the required total weight and fuel weight to perform the design mission.

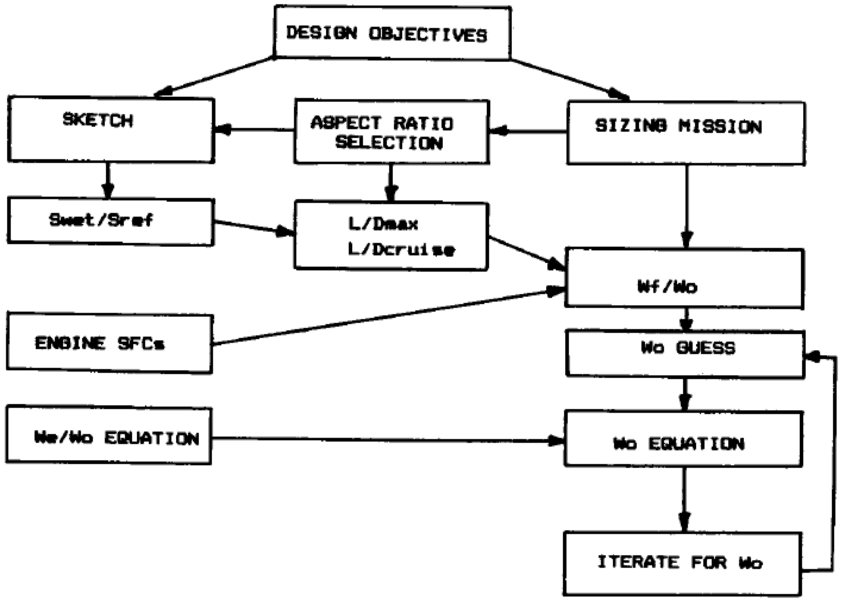
First order sizing provides the information to needed to develop an initial design layout in three view format. This three view drawing is completed with the internal arrangement in detail. The initial layout is analyzed to determine if it will perform the mission as indicated by the first-order sizing.

IV. Algorithm for Gross Take-off Weight Estimation

Following steps are involved in gross take-off weight estimation:

- Study the design objectives.
- Sizing mission starts here.
- Aspect ratio selection is done here.
- Sketch the layout in three views.
- Select L/D ratio and engine specific fuel consumption.
- Estimate fuel weight fraction.
- Select empty weight fraction (Historical trends).
- Guess initial gross weight.
- Calculate gross weight from equation.
- Iterate for gross weight by going to step8, until guess and calculated are matched.

The following flow chart explains the same algorithm as explained previous



V. Procedure

- Write the request for proposal for the given aircraft. It should be in the form of parameters and requirements for the aircraft.
- Draw the conceptual sketch of the aircraft as explained in theory.
- Draw the mission profile for the aircraft.
- What do you understand by flight vehicle design? Explain it with various examples.
- What do you understand by weight estimation and write the algorithm for gross take-off weight estimation.

VI. Result

The take-off weight can be estimated by doing the iterations, until we get,

W_0 guess = W_0 Calculated

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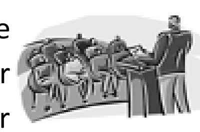

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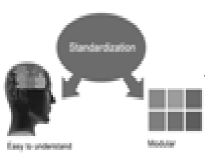

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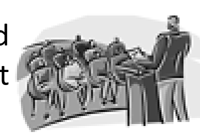

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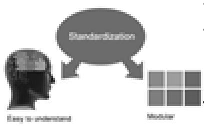

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3. Submission of Manuscripts,

4. Manuscript’s Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

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Approach:

- Single section, and succinct
- As a outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an conceptual must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

Introduction:

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from a abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.

- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

Procedures (Methods and Materials):

This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

Methods:

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

What to keep away from

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

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Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

INDEX

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ISSN 9755861