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Modeling the Civil Aircraft Operations for the Optimization of Fuel Consumption in Indian Air Transport Industry

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Abstract

This paper presents a model for the optimization of fuel consumption during the operations of civil aircrafts. Several parameters were identified which effect the aircraft fuel consumption during its operations from the literature. An informational framework was developed. It was evaluated, validated and refined. Average importance rating of decision variables was done. The unimportant variables were discarded and information refinement is done for the important and moderate variables. The information refinement is done by applying the Principal Component Analysis with the help of MS excels and a fuel optimization model was developed. Aviation model specific variables can be selectively simulated to obtain the fuel consumption optimization model for that particular product. Further we hope our work will serve its intended purpose by its industrial implementation and will actually help reduce aviation fuel consumption.

Keyword: Air transport industry**,** Aircraft operations, Aviation turbine fuel (ATF), Fuel consumption, Fuel optimization

1. Introduction

Today the growth of the Indian air transport industry is increasing at rapid rate due to the various economical and technological reasons. Due to the adaption of the open sky policy in 1990 and several other liberalization policies by the Indian government causes the rapid changes and rapid transformation in the airline industry. The Indian civil aviation too is presently witnessing a boom with a host of private airlines taking to the skies. Beside this growth the Indian airline industry also facing some of the major challenges like high aviation turbine fuel prices, overcapacity, huge debt, poor infrastructure, employees' shortage, reserve routes and intense competition [1,2]. After the liberalization in Indian civil aviation industry increased airlines choice, reduced fares, and increased routes were the major advantages. But the most restricted industry faced the some serious problem after liberalization and these were infrastructure bottleneck, traffic jam, taxation policy, and productivity [3]. Indian civil aviation has experienced a greater growth rate since middle of the past decade and the domestic traffic tripled from approximately 15 to 45 million passengers in the period between 2004 to 2010.Global aircrafts fuel consumption is expected to rise by 3% to 3.5% and reach between 461Mt and 541Mt in 2036. Domestic and international operations accounts for 38% and 62% of global fuel consumption respectively. Due to higher rate of growth in air transportation network in India resulted in increased fuel consumption of ATF and it went up by about 40% from 3.3 Mt to 4.6 Mt between 2005 and 2010 [4]. Figure 1 shows trends in fuel consumption of aviation turbine fuel (ATF). It shows continuously increased fuel consumption from 1970 to 2010 and 3.86 % growth rate of 2009-10 over 2008-09 [5].

Economy of a country largely depends on fuel prices. Increases in fuel prices affect the airlines in two ways; direct impact on the operating cost, and declines the demand for air travel and air cargo. Figure 2 shows the ATF Prices at 4 metros including sales tax for domestic airlines and Figure 3 shows the ATF Prices at 4 metros excluding sales tax for international airlines are as under (Sales Tax is not applicable to international airlines) [6]. Figure 4 shows comparison of ATF rates (Rupees/Kl) from 2004 to 2007. It showed that the ATF rates of Indian airline are higher than the Bangkok, Singapore, Kuala Lumpur, and Sharjah airlines [7].

Fuel consumption is one of major direct operating cost parameter in the air transport industry [8, 9]. Airbus, (2008) predicted that in 2003, fuel represented about 28% of total operating cost for a typical A320 family operator. By 2006 fuel prices had more than doubled, meaning that fuel now represented about 43% of all operating costs [10]. According to Majka A., (2007) at one time fuel extraction cost and availability had little impact on the evolution of aviation industry but today fuel conservation is one of most critical concern to aviation industry [11].

There are many loop holes in the country's air transport industry. In this study aircraft fuel consumption during its operation is considered as one of the major challenge in the Indian air transport industry. Aircraft consumes large amount of fuel during its takeoff, climb, cruise, descent, and landing phases of flights. The amount of fuel consumed by an aircraft during its operation from one airport to another depends upon several factors and parameters. Most of the factors are directly controlled by airlines with proper operations planning and strategies. Good flight planning, correct aircraft loading, proper maintenance, flight procedures, and fuel tankering etc. have significant impact on aircraft fuel consumption during its operations. Airline efficiency can be increased by managing the aircraft operations properly. Through proper flight planning aircraft fuel consumption can be reduced. Weight, speed, and wind resistance are the major parameters which effect the fuel consumption to a greater extent during the operations of aircraft. Reducing the weight will reduce the fuel consumption because for lighter the engine will work less. There are several methods which reduces the weight of the aircraft. This includes the using one engine while taxing, using ground tugs for aircraft movement on ground, using ground electric power instead of onboard power, removing non essential items, and proper fuel tankering etc. Hence the aircraft fuel consumption becomes an important issue for the aircraft operations planning. Therefore in such a highly competitive environment optimization of fuel consumption is essential in the airline industry. Several parameters were identified which effect the aircraft fuel consumption during its operations from the literature. An informational framework was developed. It was evaluated, validated and refined. Average importance rating of decision variables was done. The unimportant variables were discarded and information refinement is done for the important and moderate variables. The information refinement is done by applying the Principal Component Analysis with the help of MS excels and a fuel optimization model was developed.

2. Literature Review:

Most of the studies for aviation fuel conservation were started after Arab oil embargo after 1970. David A. Pilati, (1974) explained the energy use and conservation alternative for airplanes. He evaluated the fuel saving for various energy conservation strategies and he discussed how to implement these fuel saving strategies [12]. John W. Drake, (1974) suggested the slower cruise speed, flight profile optimization, and reduced fuel tanking for fuel consumption reduction[13]. D.N. Dewees and L. Waverman, (1977) highlighted the energy conservation policies for the transport sector and they evaluated the conservation policies for railroads, trucking, bus, and including airlines [14]. D. Wayne Darnell and Carolyn Loflin, (1977); Barry Nash, (1981); John S. Stroup,and Richard D. Wollmer, (1992); Zouein, Abillama and Tohme,(2002); Khaled Abdelghany,(2005) developed the fuel management models and all these models resulted in fuel saving [15; 16; 17; 18; 19]. R. R. Covey, (1979) explained the operational energy conservation strategies in commercial aviation; he explained the twelve fuel conservation strategies and these strategies were resulted in fuel saving [20]. David J. Goldsmith, (1981) and Rob Root, (2002) suggested the airliner and airframe maintenance for the fuel saving [21; 22]. Henry S.L. Fan, (1990) discussed the fuel conservation during the ground operations. He discussed the fuel saving during single engine taxiing, and towing the aircraft between terminal area and runways [23]. Airbus report getting to grips with fuel economy, (2004); ICAO, (2005) APIRG/15-WP/41; Thomos Andrew Box, (2006) suggested the operational measures for fuel conservation and fuel burn reduction [24; 25; 26]. Pedro Miguel Faria, (2009) studied the regional airline's operational performance and appropriate enhancement techniques [27]. Raffi Babikian, (2002), and Joosung Lee, (2010) explored the operational parameters which effect the aircraft fuel consumption [28; 29].

3. Development of Informational Frame

Table 1 show the identified parameters from literature review which were discussed in section 2. These parameters effect the fuel consumption of an aircraft during its operations. The parameters are divided into primary, secondary and decision variables.

The informational framework was developed based on aircraft operations for optimization of fuel consumption in aviation industry .Those decision variables are categorized three secondary areas i.e. (1) Ground Operations, (2) Airborne Operations, (4) Descent and landing, which effect the fuel consumption directly or indirectly based on mathematical relationships and logic.

The information framework includes the broad section of 3 secondary dimensions, and 40 decision variables. These dimensions and variables are logically related. Some variables as discussed in section 2 are composite in nature and hence more inclusive that is they encompass a set of variables and are rather indicative. There is scope for differentiated segregation of decision variables under secondary dimensions which essentially are subsets of the primary dimension hence the concept of secondary dimension is developed. These are supportive dimensions to primary dimension. We have settled upon 3 secondary dimensions which broadly coordinate 40 decision variables.

4. Information Evaluation, Validation, and Refinement

After the development of the information framework the next important point is, whether the information mentioned in the framework covers each aspect of the study. Therefore the information evaluation and validation is done.

4.1 Information Evaluation

The information evaluation was done on the five point Likert scale scientifically by the experts of aviation industry and by the marketing experts on the response sheet provided to them. In order to provide exploratory answers to the research issue posed in this study, the learned experts were asked to rate each of the decision variable of information framework (table 1) in terms of degree of importance they attach with the information for making decision about parameters of fuel consumption optimization. The variables were rated on the five point Likert scale which has importance rating values from 1 to 5 as shown in following table [30]:
We obtained 97 responses from the various aviation experts of different organizations. So the sample size taken is 97.

4.2 Information Validation

After the information evaluation the entire questionnaire data is processed with MS excel. The epitome of the means, standard deviations (SDs) and ranking of importance ratings accredited by respondents to the 40 decision variables is shown in table3. Hence, for statistical analysis mean was calculated [31]. The mean importance rating ranged from 1.62 (the lowest importance rating for decision variable number 35) to 4.72 (the highest importance rating for decision variable number 19).

Now after calculating the mean importance rating value for each variable, these variables are categorized in three intervals which are: Important variables, Moderate variables and unimportant variables having importance rating between 5 to 4, 4 to 3, 3 to 1 respectively. This classification is shown in the following tables for the various variables of different primary dimensions.

Classification of aircraft operational Variables:

Important Variables	Moderate Variables	Unimportant Variables
19,13, 29, 21, 40, 28, 4 ,5, 14	24, 2, 38, 11, 12, 10 , 33, 3 ,37 , 25, 6	8, 18, 31, 26, 9, 16 ,7, 15,39, 17, 22, 20, 23, 35, 32, 30, 27, 34, 36

4.3 Information Refinement

After the classification of variables according to their importance rating, the unimportant variables were discarded and information refinement is done for the important and moderate variables. The information refinement is done by applying the Principal Component Analysis with the help of MS excels. Principal Component Analysis is a variable reduction procedure. It is useful when we have obtained data on a number of variables (possibly a large number of variables), and believe that there is some redundancy in those variables. In this case, redundancy means that some of the variables are correlated with one another, possibly because they are measuring the same construct. Because of this redundancy, we believe that it should be possible to reduce the observed variables into a smaller number of principal components variables that will account for most of the variance in the observed variables. After applying the Principal Component Analysis we obtained following set of variables having communality greater than 0.6
The information refinement resulted in a set of 9 variables, which will serve as parent set for developing fuel consumption optimization model during aircraft operations.

5. Conclusions and Future Work

Figure 5. shows the schematics of fuel consumption optimization model during the operations of aircraft. Aviation model specific variables can be selectively simulated to obtain the fuel consumption optimization model for that particular product.

Further we hope our work will serve its intended purpose by its industrial implementation and will actually help reduce aviation fuel consumption.

Today technology development is going on at a rapid rate and we can effectively make use of this technological revolution to reduce the fuel consumption of a commercial aircraft. Improvement in aircraft fuel efficiency depends upon the design of the engine and airframe products. Evolutionary developments of engine and airframe technology have resulted in a positive trend of fuel efficiency improvements. Design features are generally related to the products and aircraft configuration. The merging technology and design feature finally leads to the fuel consumption optimization. New material technology has also high impact on fuel consumption. The reduction of aircraft weight can be achieved by the introduction of new material technology and advance structural design. By adopting new technology and design Indian air transport industry can reduce the fuel consumption.

Aviation alternative fuels can also play an important for the optimization of aviation fuel consumption. Since the energy crises of 1970s, all the aircraft companies, aviation sectors, engine companies, and other government organization are working for practicality of using alternative fuel in aircraft. A viable alternative aviation fuel can stabilize fuel price fluctuation and reduce the reliance from the crude oil. Best alternative fuel amongst the alternative fuels can be compared on the basis of compatibility with current systems, fuel production technology, chemical, physical, and thermal properties of fuel.

There are many social, political, and economic factors which effect the airline fuel consumption optimization. If these factors are carefully managed then significant amount of fuel can be saved.

Indian air transport industry is also lacking in the infrastructural area. Aviation infrastructure also plays an important role in fuel consumption optimization. Infrastructure improvements present a major opportunity for fuel consumption reduction in aviation. Airport congestion and improper air traffic management increases the fuel consumption. Airport congestion occurs whenever the actual traffic demand is greater than what the system can handle without the delay. Better airport design and route redesign can also reduce the fuel consumption. A new form of Air Traffic Management is being introduced, with the aim of redesigning routes around the performance of the flight, managing the optimized use of airspace. Scientists and aviation experts worldwide are investigating improved air traffic management, route redesign, better airport design, and fuel acquisition to reduce the fuel consumption.

Technology and product design, alternate fuels and fuel properties, socio-economic and political, and aviation infrastructure are needed to blend them properly with aviation operational area. A general approach that can be used to achieve the goal i.e. optimized values of fuel consumption variables is by selection of testing aircraft, data collection from flight manual, training of neural network and implementation & generalization of the neural network to fuel consumption calculation. The feasibility of this generalized approach and its actual implementation will be scope for further investigations in this area.

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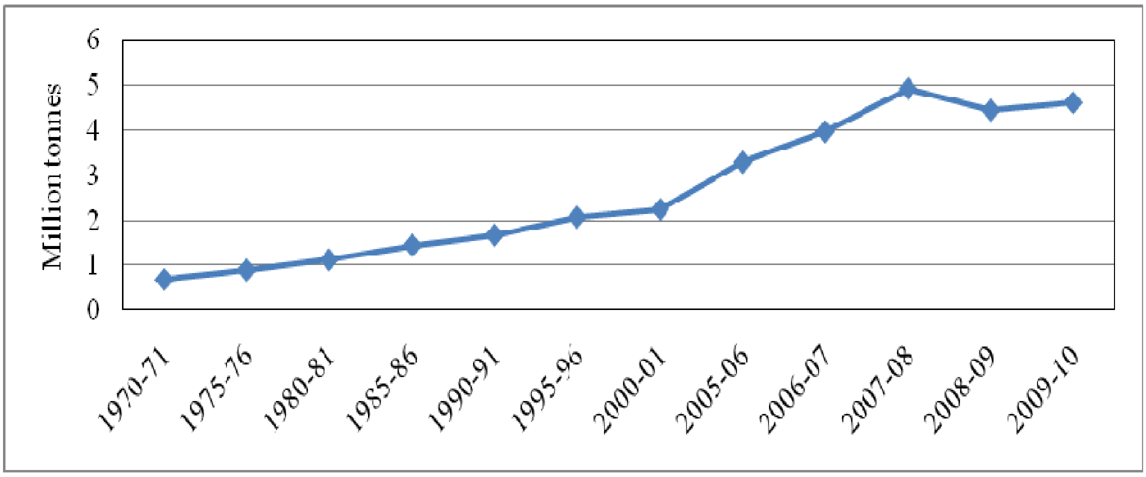

Figure 1. Trends in Consumption of Aviation Turbine Fuel (ATF) in India. Source CSO, (2011)

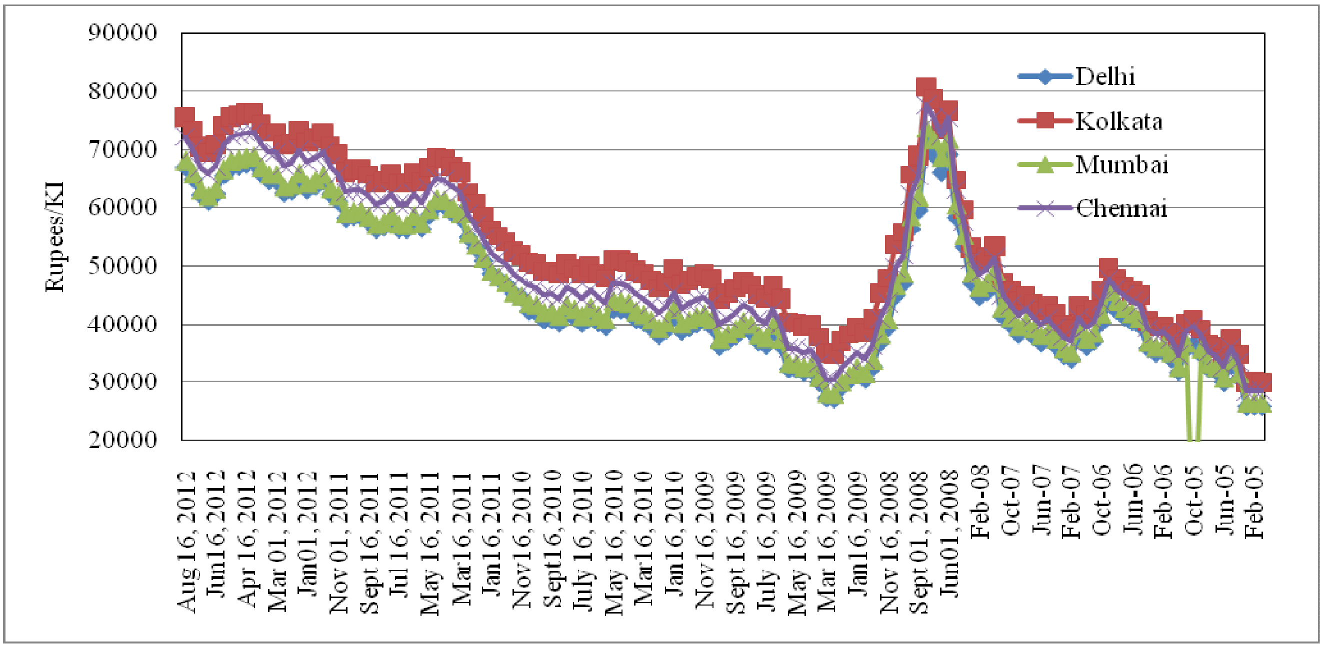

Figure. 2 ATF Prices at 4 Metros Including Sales Tax for Domestic Airlines, Source: Indian Oil [6]

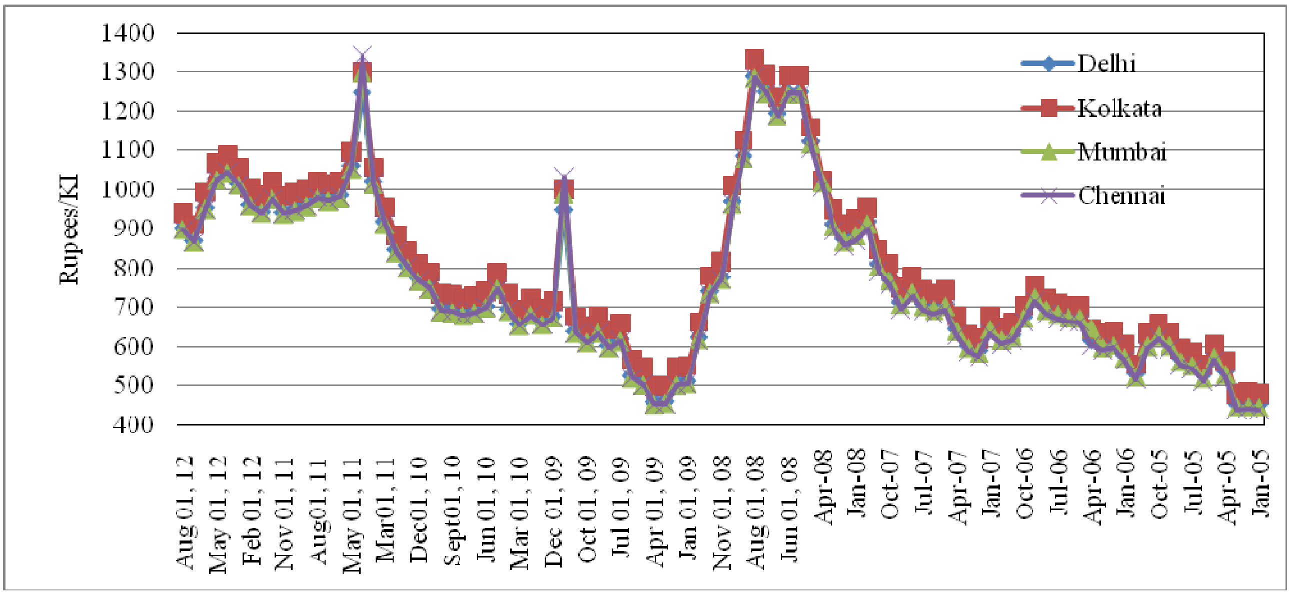

Fig. 3 ATF Prices at 4 Metros Excluding Sales Tax for international Airlines, Source: Indian Oil [6].

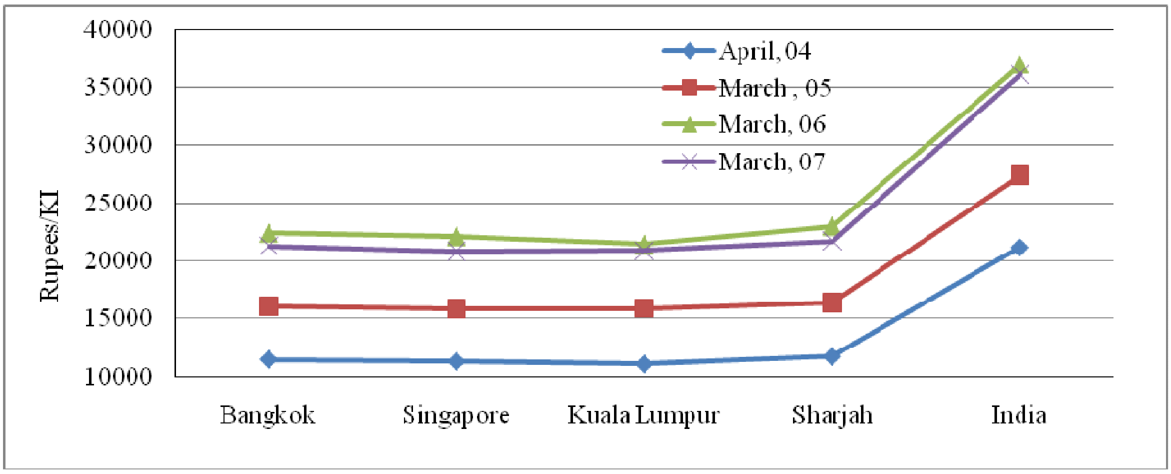

Fig. 4 Comparative ATF rates Rupees/Kl (2004-2007), Source: FIA [7]

Table1 Identified Parameters from Literature

Primary Dimension	Secondary Dimension	Decision Variable
Aircraft Operations	Ground Operations	Taxiing Fuel ferrying Maintenance Aircraft takeoff weight Aircraft landing weight Idle time Use of ground power instead of APU No. of engines operating on ground Airplane towing Aircraft replacement Refueling segments Cabin dead weight Payload Aircraft extra weight Phone coach oven weight Catering supply weight Primer paint weight Baggage weight Fuel weight Contingency fuel weight Flight profile Roll speed Roll distance
	Airborne Operations	Climb rate Flap setting Flap retraction schedule Engine power Altitude Cruise speed Air refueling Crew weight Airborne hours Block hours Flight hours Aircraft balance Cost of index for flight path Pilot techniques
	Descent and Landing	Descent speed Angle of descent Stage length

Table 2: Five point Likert scale

Degree of Importance	Value
Very important	5
Important	4
Neither important nor unimportant	3
Less important	2
Unimportant	1

Table 3 Ranking of Operational decision variables

S.No.	Decision Variable	Mean Importance Rating	Standard Deviation	Ranking
1	Taxiing	2.96	0.88	21
2	Fuel ferrying	3.95	0.75	11
3	Maintenance	3.56	0.93	17
4	Aircraft takeoff weight	4.06	0.90	7
5	Aircraft landing weight	4.02	0.67	9
6	Idle time	3.01	0.97	20
7	Use of ground power instead of APU	2.74	0.97	28
8	No. of engines operating on ground	2.89	0.85	22
9	Airplane towing	2.80	0.98	26
10	Aircraft replacement	3.69	0.86	15
11	Refueling segments	3.83	0.92	13
12	Cabin dead weight	3.76	0.76	14
13	Payload	4.43	0.87	2
14	Aircraft extra weight	4.03	0.84	8
15	Phone coach oven weight	2.72	0.68	29
16	Catering supply weight	2.76	0.69	27
17	Primer paint weight	2.61	0.68	31
18	Baggage weight	2.88	0.75	23
19	Fuel weight	4.72	0.70	1
20	Contingency fuel weight	2.27	0.66	33
21	Flight profile	4.31	0.77	4
22	Roll speed	2.46	0.97	32
23	Roll distance	2.12	0.69	34
24	Climb rate	3.96	0.77	10
25	Flap setting	3.06	0.94	19
26	Flap retraction schedule	2.83	0.94	25
27	Engine power	1.88	0.65	38
28	Altitude	4.07	0.79	6
29	Cruise speed	4.37	0.99	3
30	Air refueling	1.90	0.74	37
31	Crew weight	2.84	0.83	24
32	Airborne hours	1.91	0.85	36
33	Block hours	3.64	0.74	16
34	Flight hours	1.86	0.70	39
35	Aircraft balance	2.04	0.68	35
36	Cost of index for flight path	1.62	0.71	40
37	Pilot techniques	3.17	0.98	18
38	Descent speed	3.90	0.72	12
39	Angle of descent	2.71	0.86	30
40	Stage length	4.25	0.89	5

Table 4: Refined Set of Variables

Factors	Dimensions	Communality	Variance
Operational variables	1.Fuel Weight	0.79	15.8
	2.Payload	0.97	
	3.Cruise Speed	0.85	
	4.Flight Profile	0.94	
	5.Stage Length	0.67	
	6.Altitude	0.89	
	7.Aircraft takeoff weight	0.73	
	8.Aircraft landing weight	0.64	
	9. Extra Aircraft Weight	0.77	

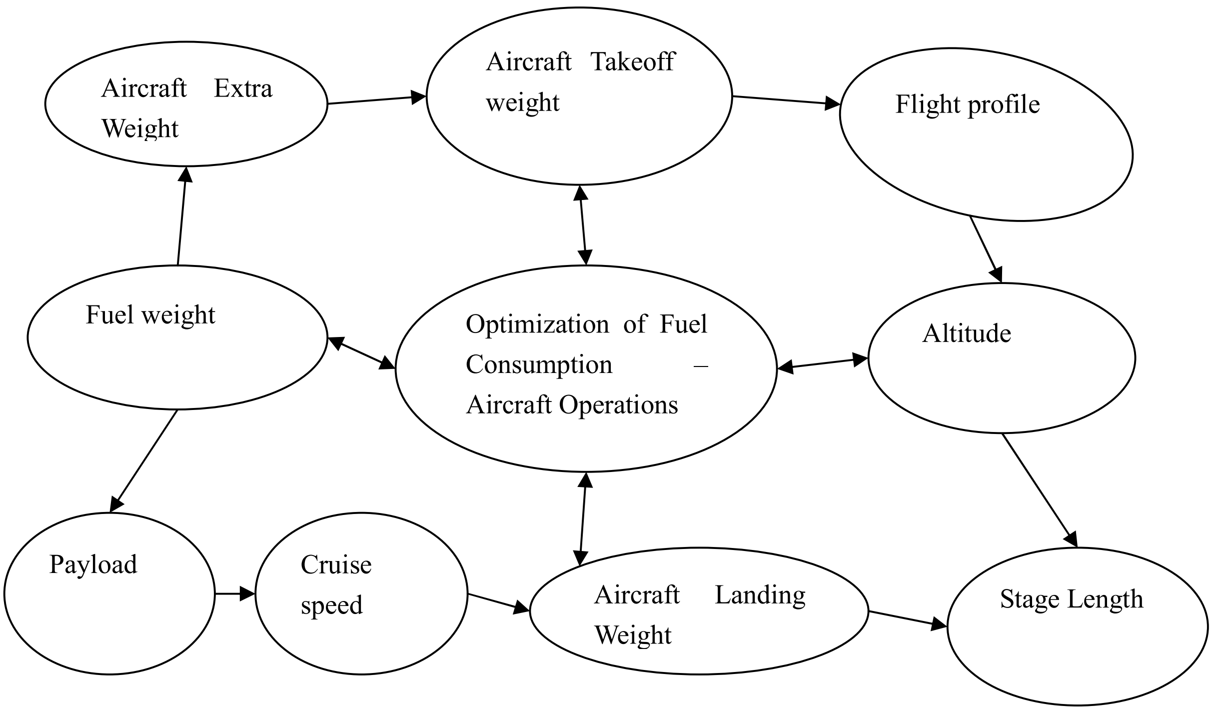

Figure 5 Schematic of Optimization of Fuel Consumption Model