The Impact of Green Taxiing Systems Using on Airport

Weijun Pan, Youjun Ye, Xiaolin Li, Zhilin Li and Qingyu Zhang

ABSTRACT

The aircraft’s engine isn’t designed for taxiing on the ground. This article describes the green taxiing systems and compares their advantages and disadvantages. Setting the Beijing Capital International Airport as an example, the taxiing fuel consumption and pollutant emissions calculation model were established. This paper calculates the total fuel consumption and pollutant emissions of the different modes in one year. The results show that the green taxiing systems can significantly reduce fuel consumption and HC, CO, CO$_2$, NOx emissions. TaxiBot is better for reducing fuel consumption and NOx emissions.

INTRODUCTION

In order to achieve the goal of zero emission taxiing in the airport, the companies developed the green taxiing systems. Israel Aerospace Industries (IAI) developed TaxiBot; Wheel Tug developed the Wheel Tug. Honeywell and Safran Group developed EGTS (Electric Green Taxiing System); Honeywell has left the joint venture company, but the Safran Group continues to implement the plan. The main components of the TaxiBot are pilot-operated semi-robotic towbarless tractor and pilot-operated human machine interface (HMI). This technology makes it possible to improve the aircraft's taxiing operation and doesn’t require significant changes to the aircraft’s taxiing procedures. WheelTug is installed in the front wheel of the dual motor and aircraft auxiliary power unit (APU) constitute. The EGTS
consists of an electric motor mounted on a wheel on the main landing gear of the aircraft and an aircraft auxiliary power unit (APU). The green taxiing systems enable the aircraft to taxi from the gate to the runway without engine operation. The advantages and disadvantages of the green taxiing systems are shown in Table I.

**GREEN TAXIING SYSTEMS USED ON THE AIRPORT**

**Calculation of Fuel Consumption and Emissions of Aircraft**

In recent years, the goal of energy conservation and pollutant emissions reduction has been put on the agenda, low-carbon economy has become a new trend in the world. During the taxiing, the fuel is not fully combusted and cause lots of pollutant gas. Therefore, the green taxiing systems on the aircraft and pollution of gas and carbon dioxide emissions reduction calculation in the airport ground taxiing

**TABLE I. THE ADVANTAGES AND DISADVANTAGES OF THE GREEN TAXIING SYSTEMS.**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>TaxiBot</th>
<th>WheelTug</th>
<th>EGTS</th>
</tr>
</thead>
</table>
|            | 1. Reduce airport conflicts  
2. The adhesion to the ground is stronger and the security is higher  
3. Does not increase the fatigue load on the nose gear, will not shorten the life of the nose gear  
4. Flexible operation, no weight limit, powerful power  
5. Almost no modification changes to the aircraft  
6. Got The Supplement Type Certificate (STC) | 1. Reduce the pushback time and save the taxi time  
2. The price is relatively cheap  
3. Reduce staff work load  
4. No need to monitor the tractor | 1. Reduce the pushback time and save the taxi time  
2. The price is relatively cheap  
3. Reduce the number of staff coming to the job  
4. Drive better  
5. No need to monitor the tractor |
| Disadvantages | 1. The price is expensive and the buyer's finance will be difficult  
2. Occupy the airport space, including on the taxiway, there may be an accident  
3. Operators need to build a warehouse at the airport, equipped with operational management personnel and to ensure its normal operation of the supporting facilities | 1. Increase the weight of the aircraft  
2. If the aircraft take off interruption to make the landing gear overheating, will affect the aircraft brake  
3. It is not yet available for large aircraft because of the APU power limit  
4. No Supplement Type Certificate (STC) | 1. Increase the weight of the aircraft  
2. If the aircraft take off interruption to make the landing gear overheating, will affect the aircraft brake  
3. It is not yet available for large aircraft because of the APU power limit  
4. No Supplement Type Certificate (STC) |
| Common Features | 1. Save a lot of fuel  
2. Reduce emissions of pollutants  
3. Reduce noise pollution  
4. To prevent foreign object debris (FOD), increase the engine life | | |
is particularly important. The LTO cycle under the International Standard Atmosphere (ISA) is divided into four modes, with different engine power setting at each mode. Table II lists the four modes of CFM56-7B20 engine emissions data.

The formula for calculating the total fuel consumption of aircrafts is as follows:

\[ F_t = \sum_a (n_a \times t_a \times FF_a) \]  

(1)

Where, \( n_a \) is the number of engines of the aircraft type a, \( t_a \) is the taxiing time of the aircraft type a (s), and \( FF_a \) is the fuel flow of the single engine for the aircraft type a (kg/s).

The total amount of emissions from aircraft is calculated as follows:

\[ E_t = \sum_i E_i \]  

(2)

Where, \( E_t \) is the total amount of emissions per week (kg), and \( E_i \) is the one-week emissions for the pollutant i (kg).

The calculation formula for \( E_i \) is as follows:

\[ E_i = \sum_a (n_a \times t_a \times FF_a \times E_{a,i}) \]  

(3)

Where, \( E_{a,i} \) is the emission indices of pollutant i for single engine aircraft type a.

**Calculation of Fuel Consumption and Emissions When Green Taxiing Systems Work on Aircraft**

The current TaxiBot is a hybrid tractor. This article uses pure electric TaxiBot, which is the development trend of taxiBot. The current WheelTug and EGTS can not be used for wide body aircraft and Jumbo-Wide Body aircraft. This article uses Wheel Tug and EGTS which are suitable for all aircrafts. They are the development trend of WheelTug and EGTS. The green taxiing systems will work with APU. Now, the emissions data for the aircraft engine has been made public, the APU emission data has not been made public. We made the following classification of the Beijing airport in table III. In this article, there are three power settings for APUs: No-Load.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time(min)</th>
<th>Power Setting (%)</th>
<th>Fuel Flow(kg/s)</th>
<th>Emissions Indices (g/kg)</th>
<th>HC</th>
<th>CO</th>
<th>NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle/Taxi</td>
<td>26</td>
<td>7</td>
<td>0.094</td>
<td>3.84 43.31</td>
<td>3.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach</td>
<td>4.0</td>
<td>30</td>
<td>0.268</td>
<td>0.08 5.03</td>
<td>7.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climb-out</td>
<td>2.2</td>
<td>85</td>
<td>0.746</td>
<td>0.03 0.23</td>
<td>13.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Take-off</td>
<td>0.7</td>
<td>100</td>
<td>0.896</td>
<td>0.03 0.15</td>
<td>15.61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data source: ICAO Aircraft Engine Emissions Databank[1].

---

286
TABLE III. AIRCRAFT TYPES AND AUXILIARY POWER UNITS GROUPED BY AIRCRAFT CATEGORY

<table>
<thead>
<tr>
<th>Aircraft Category</th>
<th>Example Aircraft Types</th>
<th>Representative APUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Body</td>
<td>B763,B772,ABY, B762, B764, A310-200, B773, A310-300 , B787B788,B789,B767ER,76F,77F,77X,B747SP</td>
<td>GTCP 331-350, PW-980, GTCP 660,PW901A.</td>
</tr>
<tr>
<td>Jumbo-Wide Body</td>
<td>MD11, B744, A332 A330, A342, B747, A333, A346, A343, A380,74N</td>
<td></td>
</tr>
</tbody>
</table>

(NL), Environmental Control System (ECS), and Main Engine Start (MES). No-Load (NL) is Lowest power setting used during the “APU Start” mode. Environmental Control System (ECS): Normal running condition used to support the “Gate In” and “Gate Out” modes. Main Engine Start (MES): Highest power setting used to support the start of the main engines. When the TaxiBot tow aircraft, although the aircraft engine is closed, but still use the APU to provide the aircraft power and ventilation needs. Power demand is low. In this paper, the fuel flow and emission indices in No-Load (NL) mode, as shown in the table IV. When WheelTug and EGTS act on aircraft front landing gear wheels and main landing gear wheels, they are powered by APU. The aircraft’s engine is in the closed state, so during the taxiing will only APU consumption of fuel and emissions of pollutants. WheelTug and EGTS require a lot of power to drive the motor in operation. This article uses the fuel flow and emission indices in the Main Engine Start (MES) mode, as shown in the table IV.

In the m condition (m=No-Load (NL) or Main Engine Start (MES)), the total fuel consumption $WF_{m,t}$ is calculated as follows:

$$WF_{m,t} = \begin{cases} \sum_a \left[ (t_{b,m} \times WFF_{a,m}) + (240n_a \times FF_a) \right] (\text{taxi – out}) \\ \sum_a \left( t_{b,m} \times WFF_{a,m} \right) (\text{taxi – in}) \end{cases}$$

TABLE IV. APU FUEL FLOW AND EMISSIONS INDICES FOR THE MES CONDITION AND NL CONDITION.

<table>
<thead>
<tr>
<th>Aircraft Category</th>
<th>Sorties</th>
<th>Fuel Flow(kg/s)</th>
<th>Emissions Indices (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MES</td>
<td>NL</td>
</tr>
<tr>
<td>Narrow Body</td>
<td>8794</td>
<td>0.038</td>
<td>0.021</td>
</tr>
<tr>
<td>Wide Body</td>
<td>1627</td>
<td>0.064</td>
<td>0.035</td>
</tr>
<tr>
<td>Jumbo - Wide Body</td>
<td>2534</td>
<td>0.058</td>
<td>0.033</td>
</tr>
</tbody>
</table>

Where, $t_{b,m}$ is the time of green taxiing system working on the aircraft under m condition. $WFF_{a,m}$ is the APU fuel flow of the aircraft type a under m conditions (kg/s). 240 is the time for aircraft preheat their engines before take-off(s).

The total amount of pollutant emissions from APU pollution is calculated as follows:

$$WE_{m,t} = \sum_i WE_{m,i}$$

Where, $WE_{m,t}$ is the total amount of emissions under m conditions. $WE_{m,i}$ is the weekly emissions of pollutants i under m condition (kg).

Aircraft pollutant emissions in the week of emissions calculation formula $WE_{m,i}$ as follows:

$$WE_{m,i} = \left\{ \frac{\sum_a \left( t_{b,m} \times WFF_{a,m} \times WE_{a,m,i} \right) \left( taxi-out \right)}{\sum_a \left( t_{b,m} \times WFF_{a,m} \times WE_{a,m,i} \right) \left( taxi-in \right)} \right\} \left( taxi-out \right) + \left( \left( 240 n_a \times FF_a \times E_{a,i} \right) \right) \left( taxi-out \right)$$

Where, $WE_{a,m,i}$ is aircraft type a pollutant emission index for the pollutant i of the APU under m conditions.

**Calculation of Carbon Dioxide Emissions**

According to the "China Civil Aviation Enterprise Greenhouse Gas Emissions Accounting Method and Reporting Guide (Trial)"[3], the formula for calculating the total amount of carbon dioxide emitted from aviation kerosene can be calculated as follows:

$$E_{ak} = 3.1515 \times F_m$$

Where, $E_{ak}$ is the total amount of carbon dioxide emitted from aviation kerosene (t), $F_m$ is total fuel consumption (t).

**Calculation and Analysis**

According to the Beijing Capital International Airport flight plan, the flights of a week were counted. The types of aircraft were shown in Table V.

In this paper, for the fuel flow during the taxing period, this paper uses 7% of the power setting level fuel flow and the pollutant emissions indices to calculate the aircraft taxing fuel consumption and pollutant emissions. The data from the ICAO aircraft engine emissions is shown in Table V.

According to the "2015 National Civil Aviation Flight Operation Efficiency Report"[4]of China, we take the average taxi time of 24.45 minutes. According to formula (1) - (7), the data of the table VI can be obtained.

As shown in Figure 1, Wheeltug/EGTS and TaxiBot can reduce fuel by 79.95%,
TABLE V. AIRCRAFT INFORMATION AND ITS FUEL FLOW, POLLUTANT EMISSIONS.

<table>
<thead>
<tr>
<th>Aircraft model</th>
<th>Sortie</th>
<th>Engine model</th>
<th>Quantity</th>
<th>Fuel Flow (kg/s)</th>
<th>HC (g/s)</th>
<th>CO(g/s)</th>
<th>NOx(g/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A319</td>
<td>567</td>
<td>CFM56-5A4</td>
<td>2</td>
<td>0.095</td>
<td>0.166</td>
<td>1.929</td>
<td>0.3838</td>
</tr>
<tr>
<td>A320</td>
<td>1430</td>
<td>CFM56-5A3</td>
<td>2</td>
<td>0.104</td>
<td>0.136</td>
<td>1.691</td>
<td>0.4280</td>
</tr>
<tr>
<td>A321</td>
<td>1981</td>
<td>CFM56-5B3/3</td>
<td>2</td>
<td>0.113</td>
<td>0.124</td>
<td>2.892</td>
<td>0.5198</td>
</tr>
<tr>
<td>A332</td>
<td>1012</td>
<td>CF6-80E1A4</td>
<td>2</td>
<td>0.227</td>
<td>2.349</td>
<td>8.646</td>
<td>1.0487</td>
</tr>
<tr>
<td>A333</td>
<td>1156</td>
<td>CF6-80E1A2</td>
<td>2</td>
<td>0.228</td>
<td>2.686</td>
<td>9.729</td>
<td>1.0328</td>
</tr>
<tr>
<td>A342</td>
<td>16</td>
<td>CFM-56-5C2</td>
<td>4</td>
<td>0.118</td>
<td>0.667</td>
<td>3.995</td>
<td>0.4923</td>
</tr>
<tr>
<td>A343</td>
<td>2</td>
<td>CFM-56-5C4</td>
<td>4</td>
<td>0.124</td>
<td>0.62</td>
<td>3.835</td>
<td>0.5307</td>
</tr>
<tr>
<td>A346</td>
<td>21</td>
<td>Trent 556-61</td>
<td>4</td>
<td>0.23</td>
<td>0.023</td>
<td>2.369</td>
<td>1.4237</td>
</tr>
<tr>
<td>A380</td>
<td>70</td>
<td>Trent 972-84</td>
<td>4</td>
<td>0.27</td>
<td>0.065</td>
<td>4.304</td>
<td>1.35</td>
</tr>
<tr>
<td>73F</td>
<td>262</td>
<td>CFM56-3B-2</td>
<td>2</td>
<td>0.119</td>
<td>0.208</td>
<td>3.582</td>
<td>0.4879</td>
</tr>
<tr>
<td>B737</td>
<td>438</td>
<td>CFM56-7B20</td>
<td>2</td>
<td>0.094</td>
<td>0.361</td>
<td>4.071</td>
<td>0.3544</td>
</tr>
<tr>
<td>B738</td>
<td>3995</td>
<td>CFM56-7B24</td>
<td>2</td>
<td>0.109</td>
<td>0.262</td>
<td>2.398</td>
<td>0.4796</td>
</tr>
<tr>
<td>B752/B75F</td>
<td>111</td>
<td>RB211-535E4B</td>
<td>2</td>
<td>0.19</td>
<td>0.053</td>
<td>2.234</td>
<td>0.6688</td>
</tr>
<tr>
<td>B747/B747SP/B74N</td>
<td>116</td>
<td>RB211-524D4</td>
<td>4</td>
<td>0.26</td>
<td>0.367</td>
<td>2.418</td>
<td>1.1466</td>
</tr>
<tr>
<td>B744</td>
<td>131</td>
<td>PW4164</td>
<td>4</td>
<td>0.21</td>
<td>0.937</td>
<td>5.601</td>
<td>0.8463</td>
</tr>
<tr>
<td>B763/76F</td>
<td>148</td>
<td>CF6-80C2B7F</td>
<td>2</td>
<td>0.188</td>
<td>0.350</td>
<td>4.053</td>
<td>0.8498</td>
</tr>
<tr>
<td>B772</td>
<td>288</td>
<td>PW4077</td>
<td>2</td>
<td>0.232</td>
<td>0.696</td>
<td>4.686</td>
<td>0.9744</td>
</tr>
<tr>
<td>B773</td>
<td>609</td>
<td>GE90-92B</td>
<td>2</td>
<td>0.304</td>
<td>0.112</td>
<td>3.809</td>
<td>1.7997</td>
</tr>
<tr>
<td>B787</td>
<td>212</td>
<td>GEnx-1B54</td>
<td>2</td>
<td>0.184</td>
<td>0.247</td>
<td>4.802</td>
<td>0.7323</td>
</tr>
<tr>
<td>B788/B789</td>
<td>310</td>
<td>GEnx-1B64</td>
<td>2</td>
<td>0.199</td>
<td>0.161</td>
<td>4.302</td>
<td>0.8438</td>
</tr>
<tr>
<td>77F/77X</td>
<td>50</td>
<td>GE90-110B1</td>
<td>2</td>
<td>0.37</td>
<td>1.684</td>
<td>15.018</td>
<td>1.8907</td>
</tr>
<tr>
<td>MD11</td>
<td>10</td>
<td>PW4460</td>
<td>3</td>
<td>0.213</td>
<td>0.354</td>
<td>4.328</td>
<td>1.0437</td>
</tr>
<tr>
<td>Tu204</td>
<td>10</td>
<td>RB211-535E4</td>
<td>2</td>
<td>0.19</td>
<td>0.19</td>
<td>2.934</td>
<td>0.817</td>
</tr>
<tr>
<td>ABY</td>
<td>10</td>
<td>PW4158</td>
<td>2</td>
<td>0.211</td>
<td>0.376</td>
<td>4.429</td>
<td>1.0128</td>
</tr>
</tbody>
</table>

85.13%, reduce HC emissions by 83.0%, 77%, reduce CO emissions by 90.39%, 86.06%, reduce NOx emissions by 67.28%, 83.5%. The price of aviation kerosene is 3213 RMB/ton. Wheeltug / EGTS, TaxiBot can save 791 million RMB, 844 million RMB of aviation kerosene.

TABLE VI. TAXIING FUEL CONSUMPTION AND THE POLLUTANT EMISSIONS OF DIFFERENT TAXIING MODES IN A YEAR.

<table>
<thead>
<tr>
<th>category</th>
<th>Total fuel consumption(t)</th>
<th>HC emissions(t)</th>
<th>CO emissions(t)</th>
<th>NOx emissions(t)</th>
<th>CO2 emissions(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>aircraft</td>
<td>301519.13</td>
<td>1338.640</td>
<td>9428.080</td>
<td>1486.538</td>
<td>950735.057</td>
</tr>
<tr>
<td>WheelTug/E GTS</td>
<td>76023.57</td>
<td>206.35</td>
<td>1402.67</td>
<td>407.86</td>
<td>76023.57</td>
</tr>
<tr>
<td>TaxiBot</td>
<td>56318.45</td>
<td>312.08</td>
<td>1950.25</td>
<td>332.74</td>
<td>56318.45</td>
</tr>
</tbody>
</table>
CONCLUSIONS

This paper describes the characteristics of the green taxiing systems and analyzes the advantages and disadvantages of the three taxiing systems according to their characteristics. Wheel tug / EGTS and TaxiBot can reduce fuel consumption and CO2 emissions by 79.95%, 85.13%. Wheel tug / EGTS, TaxiBot can save 791 million RMB, 844 million RMB in a year. The green taxiing systems have a positive impact on the airline and the airport.

ACKNOWLEDGEMENTS

This research was sponsored by National Nature Science Foundation of China (Project No.U1433126).

REFERENCES


Figure 1. Different taxi modes’ fuel consumption and CO2, HC, CO, NOx emissions.