TAKEOFF2.c 12 May 1994

by Sean Lynn, and converted to c by Pete MacMillin, with improved numerics

TAKEOFF2.c is a c implementation of a modified approach proposed by Krenkel and Salzman to solve for aircraft takeoff. The original methodology solved the aircraft equations of motion parametrically, whereas this program solves through a time-step integration technique. The methodlology was also modified to calculate Balanced Field Length (BFL) for preliminary design purposes. Balanced field length is often, as here, defined as the distance required to make either a One Engine Inoperative (OEI) takeoff (including obstacle passage) or a braked stop when an engine fails at critical engine failure speed.

Krenkel and Salzman assumed thrust vectoring capability and thrust variation with velocity to create the balance of forces equations on the aircraft during its takeoff run. All necessary input parameters can be obtained from the performance parameters necessary for preliminary aircraft design. Some sources for estimating design parameters are located below.

The program is broken into two parts, each describing different aspects in a takeoff analysis:

1) Normal Takeoff - From stop to liftoff to passage over a 35ft (11m)obstacle.
2) Balance Field Length calculation - Interative solution to find where the engine can fail so that the distance to perform a OEI takeoff is equal to the distance to brake to a stop.

Each section prints out important times, distances and velocities for the takeoff run. For normal takeoff , incremental time distance and velocity data is output as well.

References

Krenkel, A.R., Salzman, A., "Takeoff Performance of Jet-Propelled Conventional and Vectored Thrust STOL Aircraft", *Journal of Aircraft,* Vol. 5, No. 5, 1968, pp. 429.

Roskam, Jan, *Airplane Design Part 1: Preliminary Sizing of Airplanes,* Roskam Aviation and Engineering Corp., Ottawa, KS, 1989.

Torenbeek, Egbert, *Synthesis of Subsonic Airplane Design*, Kluwer Academic Publishers, Norwell, MA, 1982.

Input Format

The input is placed in a file called takeoff.in, designed to be self-explanatory and to provide a ready reference to some of the input parameters. As will be seen, each input line contains a description of the input necessary for that line. Note that all input is in English engineering units, as is the output. A sample input file is shown next.

Sample Input:

```
dc9  Mar 97 run  < case title, can be up to 80 characters long
0.002376900      < Atmospheric density (slug/ft^3)
95000.0          < Weight of aircraft (lbs)
1000.0           < Wing area (ft^2)
2.000            < CLmax - maximum lift coefficient of the aircraft
0.30             < CLgrd - lift coefficient for ground run
1.6500           < CLair - lift coefficient for climb segment
.080             < CDgrd - drag coefficient for ground run
0.121            < CDair - drag coefficient for climb segment
.025             < MUgrd - rolling friction coefficient *Note 1*
.3               < MUbrk - braking friction coefficient *Note 2*
0.0              < lambda - thrust deflection angle
1.1              < k - stall margin *Note 3*
3.0              < Time between engine failure and braking (sec) *Note 4*
35.              < Obstacle height (ft)
2                < Number of engines
31450.0  29835.0  28475.0 < 3 thrusts (lbs) *Note 5*
0.  111.6  334.0          < 3 velocities (for thrusts) (ft/s)
3.0              < Time required for rotation
2                < Print flag


Note 1:  Rolling friction coefficient is typically:
            Dry concrete/Asphalt - 0.02
            Hard turf/Gravel     - 0.04
            Short, dry grass     - 0.05
            Long grass           - 0.10
            Soft Ground          - 0.10 to 0.30

Note 2:  Braking friction coefficient is typically:
            0.20 to 0.40 with good assumptions being, 0.30 or 0.35

Note 3:  Takeoff speed is usually defined as Vto = k * Vstall, where
         k is the stall margin and Vstall is the aircraft stall speed.
         k is usually defined as 1.1, although 1.2 is also used,
         (ie. the takeoff speed is 10% to 20% higher than stall speed).

Note 4:  This is the time lag between engine failure and the decision
         to begin braking.
         (by MIL-M-007700B this is 3 sec after failure)

Note 5:  These three thrusts are used to calculate a quadratic thrust
         curve for the aircraft engine.  Each thrust should correspond
         to the velocity below it.  For cases with unknown thrust curves
         a constant thrust can be entered for three different velocities.
```

Output

The program was designed to output a variety of data to satisfy many needs. The output data is divided into three sections:

1) Echo the input case data
2) Output normal takeoff data
3) Output OEI BFL takeoff data

Each section, in turn, is divided into three sections: critical times, distances and velocity output. It is a fairly simple task to modify the data for import to a spreadsheet for graphing.

Sample Output (from Sample Input)

```
<<<<<<<<<<<<< Input Data >>>>>>>>>>>>>>
dc9 Mar 97 run

Atmospheric density      = 0.002377 (sl/ft^2)
Aircraft Weight          = 95000.000000 (lbs)
Wing area                = 1000.000000 (ft^2)
Maximum lift coefficient = 2.000000
Ground lift coefficient  = 0.300000
Air lift coefficient     = 1.650000
Ground drag coefficient  = 0.080000
Air drag coefficient     = 0.121000
Rolling friction coeff.  = 0.025000
Braking friction coeff.  = 0.300000
Angle of thrust          = 0.000000 (rad)
Stall margin (k)         = 1.100000
Descision time           = 3.000000 (sec)
Obstacle height          = 35.000000 (ft)
OEI power remaining      = 0.500000

Thrust = 31450.000000 + -17.263404 * V + 0.025019 * V^2


 Normal Takeoff >>>>>>>>>>>>>>
Time (s)     x-dist (ft)     x-Vel (ft/s)     y-dist (ft)     y-Vel (ft/s)
  0.000         0.000           0.000            0.000            0.000
  1.000         4.914           9.818            0.000            0.000
  2.507        30.796          24.499            0.000            0.000
  4.251        88.171          41.290            0.000            0.000
  6.015       175.840          58.058            0.000            0.000
  7.679       285.433          73.650            0.000            0.000
  9.032       393.639          86.169            0.000            0.000
 10.276       507.915          97.533            0.000            0.000
 11.411       624.341         107.772            0.000            0.000
 12.443       740.367         116.989            0.000            0.000
 13.385       854.499         125.311            0.000            0.000
 14.248       965.973         132.864            0.000            0.000
 15.044      1074.493         139.762            0.000            0.000
 15.783      1180.041         146.104            0.000            0.000
 16.472      1282.758         151.972            0.000            0.000
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 17.119       1382.861         157.438            0.000            0.000
 17.730       1480.600         162.558            0.000            0.000
 18.310       1576.227         167.380            0.000            0.000
 18.862       1669.986         171.944            0.000            0.000
 19.391       1762.097         176.282            0.000            0.000
 19.900       1852.764         180.423            0.000            0.000
 20.390       1942.163         184.389            0.000            0.000
 20.864       2030.452         188.198            0.000            0.000
 21.323       2117.769         191.869            0.000            0.000
 21.770       2204.232         195.413            0.000            0.000
 22.204       2289.945         198.844            0.000            0.000
 22.629       2374.997         202.170            0.000            0.000
 23.043       2459.465         205.401            0.000            0.000
 23.449       2543.417         208.545            0.000            0.000
 23.846       2626.910         211.607            0.000            0.000
 24.236       2709.994         214.594            0.000            0.000
 24.619       2792.713         217.510            0.000            0.000
 24.936       2862.147         219.912            0.000            0.000
 27.936       3555.391         242.080            0.000            0.000
 28.000       3570.887         242.517            0.014            0.436
 28.084       3591.316         243.084            0.075            1.025
 28.189       3616.811         243.777            0.222            1.781
 28.314       3647.263         244.583            0.502            2.715
 28.457       3682.379         245.482            0.971            3.832
 28.617       3721.746         246.449            1.687            5.135
 28.792       3764.890         247.460            2.713            6.620
 28.979       3811.319         248.489            4.107            8.284
 29.177       3860.555         249.511            5.925           10.118
 29.383       3912.155         250.505            8.218           12.115
 29.596       3965.718         251.451           11.032           14.264
 29.815       4020.894         252.331           14.405           16.552
 30.039       4077.380         253.132           18.373           18.969
 30.266       4134.917         253.842           22.965           21.503
 30.496       4193.289         254.450           28.205           24.140
 30.727       4252.316         254.948           34.114           26.869
 30.961       4260.314         254.999           35.000           27.246
n<<<<<<<<<<<<<< Normal Take-off Summary >>>>>>>>>>>>>>>
Rotation Velocity      =  219.912 (ft/s)
Lift-off velocity      =  242.080 (ft/s)
Velocity over obstacle =  256.451 (ft/s)
Rotation distance      = 2862.147 (ft)
Lift-off distance      = 3555.391 (ft)
Distance to obstacle   = 4260.314 (ft)
Rotation time          =   24.936 (s)
Lift-off time          =   27.936 (s)
Time to obstacle       =   30.759 (s)

n<<<<<<<<<<<<<<<<<<<<<<< OEI Take-Off Summary >>>>>>>>>>>>>>>>>>>>
Critical Velocity        =  203.886 (ft/s)
Decision Velocity        =  212.381 (ft/s)
Velocity over obstacle   =  233.529 (ft/s)
Critical Distance        = 2419.709 (ft)
Decision Distance        = 3044.195 (ft)
Balanced Field Length    = 5398.148 (ft)
Critical Time            =   22.849 (sec)
Decision Time            =   25.849 (sec)
OEI Takeoff Time         =   36.300 (sec)
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