We call “reference” satellite the satellite that is initialized in the input file as a “regular” satellite: sections #SPACECRAFTS, #ORBIT, and #ATTITUDE (optional section). We call “ensemble” satellite any satellite that has been initialized in one of the ensemble sections of the input file: sections ##ENSEMBLES\_COE, ##ENSEMBLES\_ATTITUDE, ###ENSEMBLES\_ANGULAR\_VELOCITY, ###ENSEMBLES\_ANGULAR\_VELOCITY\_DEPLOYMENT, and ###ENSEMBLES\_INITIAL\_ATTITUDE.

To run the propagator with ensembles, it is recommended to use MPI with as many processors as you can. For example, if you want to run 1000 ensembles, then the following command will run 100 satellites per processor (10 processors total):

mpirun –np 10 run\_moat name\_of\_the\_main\_input\_file

(note: if you the number of satellites is not a multiple of the number of processors then the propagator will make a truncation (ex: if you want to run 1000 satellites with 9 processors, each processor will run 111 satellites, so only 999 ensembles are run, not 1000. This ‘bug’ will be fixed in the future)).

The propagator outputs whatever is chosen in section #OUTPUT\_ENSEMBLES. You can choose:

eci\_r

eci\_v

geodetic

oe

attitude

power

density

collision

For example, let’s assume that the user choose “eci\_r, geodetic” in this section. This means that the user wants to know the ECI position and latitude/longitude/altitude of all 1000 satellites as a function of time. Of course, the propagator does not create 1000 files. Each processor creates one file per parameter. Processor 1 creates one file for X\_ECI, one file for Y\_ECI, one file for Z\_ECI, one file for latitude, one file for longitude, and one file for altitude. Same for processor 2 and so on. For example, the altitude file created by processor 1 has the altitude VS time of all satellites run by this processor (100 satellites if 10 processors are used for 1000 ensembles). Therefore, in this example, 60 files will be created (60 = 10 processors \* 6 files per processor).

These files are created in the subfolder ensemble/ of the reference satellite folder. The exact format for the name of these 60 files is:

iproc\_procNumber-numberOfProcUsed\_parameter\_output\_filename\_of\_reference\_sc

for example:

iproc\_3-10\_z\_eci\_mysat1.txt

has the Z\_ECI position VS time of the 100 satellites run by processor 3 (out of 10 processors), these 100 satellites being the ensembles satellites of the reference satellite mysat1.

These files are not directly usable: you need to concatenate all processor files for each parameter. A Python script does this: ./srcPython/concatenate\_proc.py. In the example, this script automatically creates 6 files: ensemble\_x\_eci\_mysat1.txt, ensemble\_y\_eci\_mysat1.txt, ensemble\_z\_eci\_mysat1.txt, ensemble\_latitude\_mysat1.txt, ensemble\_longitude\_mysat1.txt, and ensemble\_altitude\_mysat1.txt in the subfolder ensemble/ of the reference satellite folder and moves all the processor files in a subfolder ensemble/proc\_files. For example, ensemble\_z\_eci\_mysat1.txt has the Z\_ECI position VS time of the 1000 satellites run by all 10 processors.

To run the Python script:

1. go to ./srcPython
2. python concatenate\_prop.py name\_of\_the\_run\_dir name\_of\_the\_main\_input\_file

*Example:*

python concatenate\_prop.py run\_example example\_mysat.txt

3 main types of ensembles can be run:

* orbital elements
* attitude
* coefficient of drag

Orbital elements

Here, the user can run ensembles that are initialized by the same orbital elements as the reference spacecraft (in section #ORBIT), but with a slight change in the orbital elements.

To run ensembles on the orbital elements, go to section ##ENSEMBLES\_COE:

first line: number of ensembles to run

n next lines: standard deviations of each orbital elements of each satellite (one line per satellite (n is the number of reference spacecraft (line 7 of main input file)).

*Example:*

if you initialized 2 reference satellites in section #ORBIT:

500 35 0 70 12 0.00000001

450 85 45 20 0 0.01

and you want to run ensembles on the apogee altitude and the argument of the perigee for the first reference spacecraft and ensembles on the apogee altitude and the inclination for the second spacecraft, then in the section ##ENSEMBLES\_COE:

1000

10.0 0.0 20.0 0.0 0.0 0.0

10.0 30.0 0.0 0.0 0.0 0.0

This will run 1000 ensembles for the first satellite with random altitudes around a normal distribution that has a 10 km standard deviation and a 500 km mean, and random arguments of perigee around a normal distribution that has a 20° standard deviation and a 0° mean.

It will also run 1000 ensembles for the second satellite with random altitudes around a normal distribution that has a 10 km standard deviation and a 450 km mean, and random inclinations around a normal distribution that has a 30° standard deviation and a 85° mean.

Attitude

3 types of ensembles: ENSEMBLES\_ANGULAR\_VELOCITY or ENSEMBLES\_ANGULAR\_VELOCITY\_DEPLOYMENT or ENSEMBLES\_INITIAL\_ATTITUDE.

For any of these 3 types, the number of ensembles is chosen in section ##ENSEMBLES\_ATTITUDE (first and only line).

*ENSEMBLES\_ANGULAR\_VELOCITY:*

First line is called the delay.  
Second line is the standard deviation on the angular velocities.

*Example:*

#ATTITUDE

nadir

##ENSEMBLES\_ATTITUDE

1000

###ENSEMBLES\_ANGULAR\_VELOCITY

300

(0.033; 0.033; 0.033)

The reference spacecraft is nadir pointing (first and only line of section #ATTITUDE). Therefore, the 1000 ensemble spacecraft (first and only line of section ##ENSEMBLES\_ATTITUDE) are nadir pointing every 300 seconds (first line of section ###ENSEMBLES\_ANGULAR\_VELOCITY) and drift from this reference attitude for 300 seconds with initial pitch, roll, and yaw angular velocities that are randomly distributed following a normal distribution with a standard deviation of 0.033 °/s (same for the three angular velocities here) (second line of section ###ENSEMBLES\_ANGULAR\_VELOCITY) and a mean of 0°/s (the mean cannot be set).

For now, this section here works if there is only one satellite in the constellation (first line of section #SPACECRAFT).

*ENSEMBLES\_ANGULAR\_VELOCITY\_DEPLOYMENT:*

To use this section, you need to put ensemble\_angular\_velocity in section #ATTITUDE.

First line is the initial attitude (pitch; roll; yaw) (this line overwrites the attitude set in section #ATTITUDE).

Second line is the mean of the normal distribution on the initial angular velocities (pitch angular velocity; roll angular velocity; yaw angular velocity).

Third line is the standard deviation of the normal distribution on the initial angular velocities (pitch angular velocity sigma; roll angular velocity sigma; yaw angular velocity sigma).

*Example:*

#ATTITUDE

ensemble\_angular\_velocity

##ENSEMBLES\_ATTITUDE

100

###ENSEMBLES\_ANGULAR\_VELOCITY\_DEPLOYMENT

(0; 0; 0)

(0; 0; 0)

(1.6; 1.6; 1.6)

This section is to represent an uncertainty on the initial angular velocity (at the deployment for example). For now, this section here works if there is only one satellite in the constellation (first line of section #SPACECRAFT).

So this section is similar to section ### ENSEMBLES\_ANGULAR\_VELOCITY except that here you do not choose any delay (the ensemble spacecraft keep drifting during the entire propagation), but you choose the initial attitude (first line) and the initial mean angular velocities of the distribution (second line).

*ENSEMBLES\_INITIAL\_ATTITUDE*

To use this section, you need to put ensemble\_initial\_attitude in section #ATTITUDE.

First line is the Mean of the normal distribution on the initial attitude (pitch; roll; yaw).

Second line is the Standard deviation of the normal distribution on the initial attitude.

Third line is the Initial angular velocity (same for all ensembles, no distribution).

*Example:*

#ATTITUDE

ensemble\_initial\_attitude

##ENSEMBLES\_ATTITUDE

100

###ENSEMBLES\_INITIAL\_ATTITUDE

(0; 0; 0)

(2.0; 0; 0.0)

(0; 0; 2.0)

This section is to represent an uncertainty on the initial attitude, assuming the angular velocity is perfectly known. For now, this section here works if there is only one satellite in the constellation (first line of section #SPACECRAFT).

Coefficient of drag

Contrarily to the ensembles on the orbital elements and the attitude, running ensembles on the drag coefficient is done in the geometry file. Please refer to the document “how\_to\_write\_the\_geometry\_file”.

*Example (with one surface in the geometry file):*

#BEGINNINGOFHEADER

#ENDOFHEADER

#NB\_ENSEMBLES\_CD

100

# Surface 1

(0.0; 0; 1.0) // normal (in body frame)

2566.0 // area (cm^2)

1860.0 // solar cell area (cm^2)

2.2, 0.2 // Cd, standard deviation on Cd

1 // solar radiation coefficient

For this surface (Surface 1), the reference spacecraft have a Cd of 2.2 (first number of fourth line of section # Surface 1). The 100 ensemble spacecraft (section #NB\_ENSEMBLES\_CD) have Cd that are randomly distributed with a normal distribution that has a standard deviation of 0.22 (second number of fourth line of section # Surface 1) and a mean of 2.2 (first number of fourth line of section # Surface 1).