Modeling the NASA Dawn Ion Propulsion Spacecraft

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Executive Summery

Last year the StarLogo program was designed to model the creation of ions for an ion propulsion engine that will be used in a spacecraft as a primary propulsion method. This year's program is a significant improvement over last year's because it shows the movements of the ions realistically in relation to time and space. We are designing our program to improve the NASA Dawn space probe, through increased ion generation in relation to solar panel size.

This year Net Logo will be used to take advantage of its greater flexibility and power in creating this model. This year the program includes the rate of ion generation over time so that any improvement in the Dawn ion engine will be shown as a decrease in fuel consumption while maintaining power in watts. This will allow the ship to go farther, even if it's not faster.

It is clear when researching the history of manned and unmanned spacecrafts that humans will continue to seek out ways of traveling farther from our home planet. Starting with the mission to the moon and hopefully not ending with the NASA Dawn.

Problem Statement

Our goal is to explore and demonstrate changes that may lead to improvements in the efficiency of ion propulsion engines. If ions are expelled with a greater force from the engine then the efficiency will be improved, because more of the work input will change to useful work output.

History of Inter Planetary Space Travel

An ion is created when an atom gains or loses electrons. In ion propulsion, an electron gun knocks electrons into a sea of xenon atoms, turning them into ions. Three charged plates accelerate the ions and send them out of the back of the rocket engine at speeds of about 77,000 mph. To avoid accumulating a negative charge, the probe shoots electrons back into the stream of xenon ions as they are leaving the engine. Ion propulsion only needs a tenth of the fuel of a chemical rocket to reach the same destination, and that means a smaller rocket is needed to launch missions, successfully. This will allow probes, such as the NASA Dawn, to orbit two separate objects, in Dawn's case the asteroid Vesta in 2011 and the dwarf planet Ceres in 2015.

One of the disadvantages to the ion engines is that, although it only requires a tenth of the fuel needed by a chemical thruster, it lacks power. Marc Rayman, chief engineer on the Dawn mission, has labeled ion propulsion "acceleration with patience."

Deep Space 1

In 1998, Deep Space 1 became the first spacecraft to use ion propulsion to reach a destination in the solar system. Using more than 160 lbs. of xenon, the probe showed a dozen new technologies and flew by two asteroids. Deep Space 1 went on operating its ion engine for 678 days, the longest any propulsion system had continuously run; the Dawn mission is expected to surpass this record.

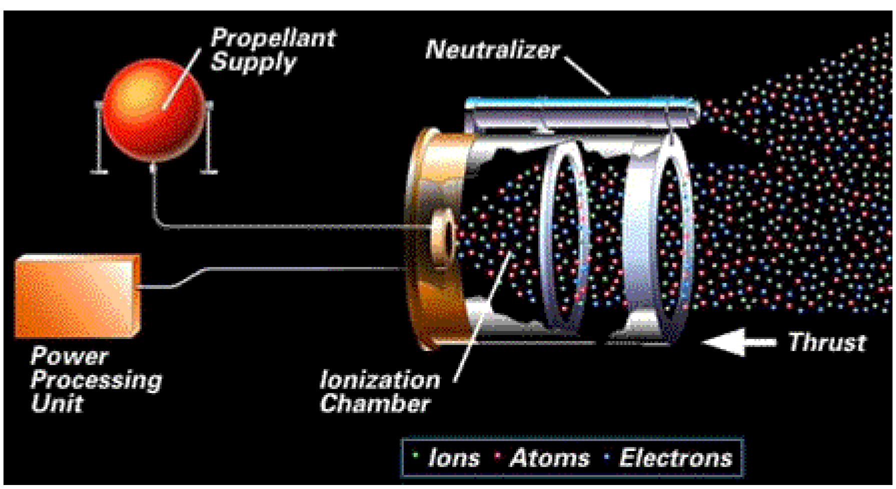
Hayabusa

The Hayabusa is a Japanese space probe built to investigate an asteroid and use new technology to bring back samples of an asteroid's surface to earth. Japan has realized a mission that uses a small spacecraft for a discovery of a very approachable asteroid and the development of a highly efficient electric propulsion system for the spacecraft is a brilliant advancement.

In November 2005, Hayabusa suffered a serious fuel leak right after its second successful touching down on the surface of Itokawa, an asteroid near Earth. Since the extra engines were not available, the strong disturbance occurred on December 8th and caused the communication to be lost since then.

How an Ion Engine Works

The integrated defense system of Boeing Ion Propulsion Center is now part of Boeing's newest part of the Boeing Satellite Development Center. Boeing has created the world's first commercial satellite to carry a brand new propulsion system that is ten times more efficient than the systems currently in use. The XIPS (pronounced "zips"), xenon ion propulsion system, is the combined power of four decades of research about ion propulsion as an alternative to chemical propulsion. The efficiency of crafts, such as Boeing 601 HP, or high power, and Boeing 702 satellite models, is increased efficiency allowing the reduction in propellant mass of up to 90% for a satellite designed for 12 to 15 years of work. This allows for less cost for launch, increase in satellite lifetime, and increased payload.



“Thrust is created by accelerating the positive ions through a series of gridded electrodes at one end of the thrust chamber. The electrodes, known as an ion extraction assembly, create more than 3,000 tiny beams of thrust. The beams are prevented from being electrically attracted back to the thruster by an external electron-emitting device called a neutralizer. Ions ejected by the Hughes-designed XIPS travel in an invisible stream at a speed of 30 kilometers per second (62,900 miles per hour), nearly 10 times that of its chemical counterpart. And, because ion thrusters operate at lower force levels, attitude disturbances during thruster operation are reduced, further simplifying the station keeping task (http://www.boeing.com/defense-space/space/bss/factsheets/xips/xips.html)”

With the quickly advancing world we have today, there are many problems with this technology, such as a very low thrust. Over time, as we advance even more, we will be able to use ion propulsion to send humans into space for long periods of time.

Mathematical Model

When working with our program we must assume xenon atoms all have same mass, atoms are transported equally and collisions all result in some angle of reflection. The force is calculated by let x equal the pxcor and y = pycor then the program will compute the:

sum-x (sum [field-charge-magnitude * sin (towards myself) / ((distance myself) ^ 2)] of charge-patches)

let sum-y (sum [field-charge-magnitude * cos (towards myself) / ((distance myself) ^ 2)] of charge-patches)

set field-strength (sqrt (sum-x ^ 2 + sum-y ^ 2)) ;

set field-direction (atan sum-x sum-y) ;and direction

This will allow the turtle to tell the patch it's force strength.

Within our program, one tick in the program equals millisecond, and the size of a patch is 1000 micrometers. The actual electromagnetic force acting on the particles, expressed varies for each of the three grids. The model shows a very low charge of about 100 volts, the medium of about 640. 1,280 volts will accelerate ions to 35,000 m/s.

Program Design

Our program was designed to allow the user to input the power, particle flow, and the size of the fuel tank. The program shows the speed of the ions, the acceleration rate, and the particles that have left the nozzle. The program will use time, force-scale constants and collision radii to make the particles move more realistically. The program will ultimately calculate magnitude or the patches correctly. When an ion contacts each patch it is given that patches velocity. The program is designed to set up patches and magnitude.

Results

The results of our NetLogo program show the xenon atoms moving through the engine toward the accelerator. There are bars of electrons moving in the opposite direction toward the atoms. As the atoms are hit by the electrons they change to a darker shade of red to signify the loss of an electron (when an atom loses all of its electrons it turns almost a brown color). The rest of the atom is then sent through accelerators and out the thrusters for motion. All of the electrons that are knocked off are used as extra energy.

Conclusion

In conclusion, once we have all of this data we can compare to the NASA Dawn and see if we've made an improvement or if we have deteriorated the efficiency of the craft. Improving on the efficiency of ion propulsion has been a tremendous challenge. In the future, the engine itself will likely have to be redesigned in order to maintain low fuel usage while increasing the power.

Appendix

Net Logo Code

```
globals [
   speeds
   fuel_remaining
   acceleration
   particle_left
   running?
   maxint
   time
   force-scale-constant
   collision-radius
   random-unit
   positive-magnitude
   negative-magnitude
   charge-patches
   field-patches
   electron-mass
   ion-mass
   ion-magnitude
   electron-magnitude
]

turtles-own [
   magnitude
   mass
   speed
]

breed [workers worker]
breed [ions ion]
breed [electrons electron]
breed [jets jet]
breed [charges charge]

patches-own [
   field-charge-magnitude
   field-strength
   field-direction
]

to setup
  clear-all ;This will clear everything from the model
  import-pcolors "ion-propulsion.png" ;This sets the patches to their colors
  set-globals ; this will set all the globals to their default numbers
  set-charges ;this will give the build-field command patches to perform it on
```

```
  build-field ;This calculates the direction and strength of the magnetic force
end

to set-charges
   set charge-patches (patches with [shade-of? pcolor blue]); this sets the charge-patches to every patch wit a color that is a shade of blue
   ask charge-patches [
      set field-charge-magnitude negative-magnitude ; sets the magnitude of the patches
   ]
end

to build-field
   set field-patches (patches with [pcolor = black and pycor > 9 ])
   ask field-patches [                                    ;asks the field patches to compute the force on them
      compute-force
   ]
end

to compute-force
   let x pxcor
   let y pycor
   let sum-x (sum [field-charge-magnitude * sin (towards myself) / ((distance myself) ^ 2)] of charge-patches)
   let sum-y (sum [field-charge-magnitude * cos (towards myself) / ((distance myself) ^ 2)] of charge-patches)
   set field-strength (sqrt (sum-x ^ 2 + sum-y ^ 2)) ;When these computations are finished, the turtle will tell the patch it's force strength
   set field-direction (atan sum-x sum-y) ;and direction
end

to go
  tick
  inject
  ask turtles [
     move
  ]
end

to set-globals ; This set the global variables in the model
  set fuel_remaining 100
  set particle_left 0
  set speeds 0
  set acceleration 0

  ;; CHANGE THESE BOGUS NUMBERS!!!!
  set force-scale-constant 0.003
  set positive-magnitude 50
```

```
  set negative-magnitude -50
  set electron-mass 1
  set ion-mass 1000
  set electron-magnitude -.5
  set ion-magnitude 0
  set collision-radius 0.1
end

to remove-fuel
  create-workers 1
  ask workers [setxy 0 40]
  ask workers [evaluate-row-and-move]

  end
to evaluate-row-and-move
repeat 23 [
    let row-patches patches-in-this-row
    ifelse (all? row-patches [pcolor = black]) [
        set heading 180
        ifelse (can-move? 1) [
            forward 1
        ] [
            set running? false
        ]
    ] [
        let color-patches row-patches with [pcolor != black]
        let target (min-one-of color-patches [distance myself])
        face target
        kill-row
    ]]
end

to-report patches-in-this-row
    let base-x-offset (min-pxcor - pxcor)
    let patch-list (n-values world-width [patch-at (base-x-offset + ?) 0])
    report (patch-set patch-list)
end

to kill-row
  ask workers [ repeat 5 [
   if (pcolor != black) [
        set pcolor black
    ] set heading 90 fd 1]set fuel_remaining (fuel_remaining - (100 / 25) )
     die]
end

to move
    if (xcor < (-0.5 + min-pxcor + 5)) [
```

```
        die
    ]
    ifelse (pcolor = black) [
        let new-x (speed * sin heading + (magnitude * field-strength * force-scale-constant * sin field-direction) / mass)
        let new-y (speed * cos heading + (magnitude * field-strength * force-scale-constant * cos field-direction) / mass)
;        show (list new-x new-y)
        set speed (sqrt (new-x ^ 2 + new-y ^ 2))
        set heading (atan new-x new-y)
    ] [
;        if ((pcolor = blue or pcolor = yellow) and breed = ions or breed = electrons) [
;        set particle_left (particle_left + 1)
    ]
    ifelse (can-move? speed) [
        forward speed
        if (breed = ions and magnitude < 8) [
            check-collision
        ]
    ] [
        set particle_left (particle_left + 1)
        die
    ]
end

to inject
    ; DO ELECTRONS
    if (remainder ticks 50 = 0 and fuel_remaining > 0) [
        create-ions 10 [
            setup-ion
        ]]
    if (remainder ticks 15 = 0) [    create-electrons 200 [
            setup-electron
        ]
    ]
end

to setup-ion
    let x1 (-0.5 + min-pxcor + 5 + random-float (world-width - 5))
    let x2 (-0.5 + min-pxcor + 5 + random-float (world-width - 5))
    setxy ((x1 + x2) / 2) max-pycor
    set shape "circle"
    set size 1
    set color 28
    set heading 180
    set magnitude ion-magnitude
    set mass ion-mass
    set speed .1
```

```
end

to setup-electron
    ; Probably don't need this for electrons
    let x1 (-0.5 + min-pxcor + 5 + random-float (world-width - 5))
    let x2 (-0.5 + min-pxcor + 5 + random-float (world-width - 5))
    setxy ((x1 + x2) / 2) max-pycor
    set shape "circle"
    set size .5
    set color blue
    set heading 180
    set magnitude electron-magnitude
    set mass electron-mass
    set speed .5
end

to check-collision
    let collidees (electrons in-radius collision-radius)
    if (any? collidees) [
        ask one-of collidees [
            collide
        ]
        set magnitude magnitude + 1
        set color red + 4.5 - magnitude
    ]
end

to collide
  let old-x speed * sin heading
  let old-y speed * cos heading
  let new-electron-heading heading - 90 + (180 * random-unit)
  let new-x sin heading - 0.5 * sin new-electron-heading
  let new-y cos heading - 0.5 * cos new-electron-heading
  set speed (speed / 2)
  set heading atan new-x new-y
  hatch 1 [
    set heading new-electron-heading
  ]
end

to collide-surface
end
```

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