Image Sciences Division

Space Shuttle Support Office

1
00:00:05,090 --> 00:00:03,320
the show you're about to watch concerns

2
00:00:06,950 --> 00:00:05,100
the space shuttle mission unlike any

3
00:00:09,200 --> 00:00:06,960
other you've ever seen the tethered

4
00:00:11,299 --> 00:00:09,210
satellite mission while the mission was

5
00:00:13,580 --> 00:00:11,309
successful in proving an idea that had

6
00:00:15,410 --> 00:00:13,590
only been a theory we had some hardware

7
00:00:18,529 --> 00:00:15,420
problems and the tether did not extend

8
00:00:20,540 --> 00:00:18,539
as far as we wanted it to go as often

9
00:00:22,730 --> 00:00:20,550
happens in research we learn from things

10
00:00:24,200 --> 00:00:22,740
when they go wrong here we learned

11
00:00:26,029 --> 00:00:24,210
enough to prove that this truly unique

12
00:00:29,179 --> 00:00:26,039
concept really does work

13
00:00:31,370 --> 00:00:29,189

in this program we do calculations based

14
00:00:34,160 --> 00:00:31,380
on the length we expected the tether to

15
00:00:40,000 --> 00:00:34,170
extend not how far it actually extended

16
00:00:40,010 --> 00:01:41,830
-

17
00:01:49,630 --> 00:01:44,990
an ordinary summer's day at the lake the

18
00:01:53,650 --> 00:01:49,640
Sun the water good fun and physics

19
00:01:56,290 --> 00:01:53,660
physics you might not think so but yes

20
00:01:58,970 --> 00:01:56,300
take this water skier for example

21
00:02:02,030 --> 00:01:58,980
there's a lot of basic physics involved

22
00:02:05,150 --> 00:02:02,040
in skiing there's the force of gravity

23
00:02:07,970 --> 00:02:05,160
the pull of the rope the resistance of

24
00:02:10,580 --> 00:02:07,980
the water the skier balances these

25
00:02:13,210 --> 00:02:10,590
forces and a few more to keep a stable

26
00:02:16,699 --> 00:02:13,220
center of mass gliding across the water

27
00:02:18,199 --> 00:02:16,709
but the physics is so basic he doesn't

28
00:02:21,680 --> 00:02:18,209
even have to think about it

29
00:02:23,660 --> 00:02:21,690
he just skis and if he doesn't get it

30
00:02:27,170 --> 00:02:23,670
right the first time he tries again

31
00:02:31,210 --> 00:02:27,180
until he does but in space

32
00:02:35,210 --> 00:02:31,220
we usually get only one shot at a task

33
00:02:38,050 --> 00:02:35,220
so before we do anything we analyze it

34
00:02:41,180 --> 00:02:38,060
to get the physics right the first time

35
00:02:43,670 --> 00:02:41,190
that's important because what you think

36
00:02:46,820 --> 00:02:43,680
should happen in space isn't necessarily

37
00:02:49,190 --> 00:02:46,830
what will happen let's say we want to

38
00:02:52,699 --> 00:02:49,200

speed up the orbiter to rendezvous with

39
00:02:56,930 --> 00:02:52,709
a spacecraft just ahead do we fire the

40
00:02:59,240 --> 00:02:56,940
orbiters jets to go faster no if we

41
00:03:02,240 --> 00:02:59,250
follow intuition and fire the jets to

42
00:03:04,790 --> 00:03:02,250
speed up will actually be propelled into

43
00:03:08,570 --> 00:03:04,800
a higher orbit that will end up slowing

44
00:03:10,310 --> 00:03:08,580
us down so up here in space we can't

45
00:03:12,710 --> 00:03:10,320
always depend on what we think will

46
00:03:15,140 --> 00:03:12,720
happen we have to know what will happen

47
00:03:24,300 --> 00:03:15,150
and that takes a good understanding of

48
00:03:29,010 --> 00:03:27,000
physics whether we use it to rendezvous

49
00:03:31,339 --> 00:03:29,020
with satellites in space or describe

50
00:03:34,020 --> 00:03:31,349
waterskiing on the earth has unlimited

51
00:03:39,479 --> 00:03:34,030
applications and today we have a really

52
00:03:41,699 --> 00:03:39,489
unique one to show you welcome aboard

53
00:03:43,520 --> 00:03:41,709
the space shuttle Atlantis where we're

54
00:03:46,080 --> 00:03:43,530
about to launch a new type of spacecraft

55
00:03:48,780 --> 00:03:46,090
it's called the tethered satellite

56
00:03:51,509 --> 00:03:48,790
that's because the entire time it's

57
00:03:53,580 --> 00:03:51,519
deployed it remains tethered to the

58
00:03:57,990 --> 00:03:53,590
orbiter by a two millimeter diameter

59
00:03:59,940 --> 00:03:58,000
strand of insulated copper this is one

60
00:04:03,960 --> 00:03:59,950
of the most complex missions ever

61
00:04:06,180 --> 00:04:03,970
attempted by a space shuttle crew what's

62
00:04:08,309 --> 00:04:06,190
amazing is that most of the physics that

63
00:04:10,530 --> 00:04:08,319

we use to fly the tethered satellite is

64
00:04:13,500 --> 00:04:10,540
the same physics that you study in high

65
00:04:17,069 --> 00:04:13,510
school it includes concepts like gravity

66
00:04:19,890 --> 00:04:17,079
angular momentum and center of mass in

67
00:04:22,500 --> 00:04:19,900
the next few minutes we're going to see

68
00:04:27,270 --> 00:04:22,510
how these concepts relate to the orbiter

69
00:04:29,820 --> 00:04:27,280
the satellite and the tether we begin

70
00:04:33,360 --> 00:04:29,830
the experiment by deploying the tethered

71
00:04:36,240 --> 00:04:33,370
satellite we do this from the top of a

72
00:04:40,440 --> 00:04:36,250
12 metre boom to protect sensitive parts

73
00:04:42,960 --> 00:04:40,450
of the orbiter small invisible nitrogen

74
00:04:45,690 --> 00:04:42,970
jets are used to get the satellite and

75
00:04:47,760 --> 00:04:45,700
tether in motion once they are far

76
00:04:49,830 --> 00:04:47,770
enough away from the orbiter we can turn

77
00:04:52,430 --> 00:04:49,840
the Jets off and the satellite and

78
00:04:54,800 --> 00:04:52,440
tether will continue to deploy

79
00:04:58,030 --> 00:04:54,810
what makes the satellites continue to go

80
00:05:00,470 --> 00:04:58,040
up after all you can't push on the road

81
00:05:03,260 --> 00:05:00,480
well that's where the physics comes in

82
00:05:05,210 --> 00:05:03,270
we take advantage of a force that causes

83
00:05:08,360 --> 00:05:05,220
the tether to continue extending on its

84
00:05:10,760 --> 00:05:08,370
own away from the earth it's a force

85
00:05:14,960 --> 00:05:10,770
that gets stronger as the tether gets

86
00:05:19,160 --> 00:05:14,970
longer when what is this force well its

87
00:05:22,580 --> 00:05:19,170
gravity gravity but how can gravity make

88
00:05:24,020 --> 00:05:22,590

things go up well which one of those

89
00:05:26,360 --> 00:05:24,030
things that doesn't make sense that's in

90
00:05:30,380 --> 00:05:26,370
you understand the physics so let's look

91
00:05:32,510 --> 00:05:30,390
at the physics of gravity all objects

92
00:05:36,470 --> 00:05:32,520
are cooled by Earth's gravity even

93
00:05:38,840 --> 00:05:36,480
objects in space but the further away

94
00:05:42,410 --> 00:05:38,850
from the earthly objects are the less

95
00:05:44,510 --> 00:05:42,420
the earth gravity pulls on them Sir

96
00:05:47,810 --> 00:05:44,520
Isaac Newton described the force due to

97
00:05:50,000 --> 00:05:47,820
gravity as an inverse square law that

98
00:05:51,770 --> 00:05:50,010
means that an object two times as far

99
00:05:54,290 --> 00:05:51,780
away from the center of the earth at

100
00:05:56,440 --> 00:05:54,300
another object with the same mass fields

101
00:05:59,300 --> 00:05:56,450
only a quarter of the gravitational pull

102
00:06:01,940 --> 00:05:59,310
it's a mouthful but next to the tether

103
00:06:06,620 --> 00:06:01,950
gravity is the most important influence

104
00:06:09,860 --> 00:06:06,630
on our tethered satellite let's find out

105
00:06:11,370 --> 00:06:09,870
why we'll calculate using Newton's to

106
00:06:14,620 --> 00:06:11,380
measure the

107
00:06:16,779 --> 00:06:14,630
when the 500 kilogram satellite is in

108
00:06:18,520 --> 00:06:16,789
the cargo bay six thousand seven hundred

109
00:06:21,960 --> 00:06:18,530
kilometers from the center of the earth

110
00:06:25,469 --> 00:06:21,970
it has a certain amount of force on it

111
00:06:28,480 --> 00:06:25,479
if we extend its 10 kilometers upwards

112
00:06:31,330 --> 00:06:28,490
gravity pulls on it about 30 Newtons

113
00:06:33,640 --> 00:06:31,340

less extending it's another ten

114
00:06:35,170 --> 00:06:33,650
kilometers reduces gravity is gripped by

115
00:06:40,330 --> 00:06:35,180
another 13 Newtons

116
00:06:43,900 --> 00:06:40,340
for a total of 26 we said that gravity

117
00:06:46,749 --> 00:06:43,910
is an inverse-square force and for our

118
00:06:50,230 --> 00:06:46,759
purposes the distance involved is from

119
00:06:52,089 --> 00:06:50,240
the center of the Earth's orbit and to

120
00:06:55,600 --> 00:06:52,099
the satellite as it moved away from the

121
00:06:57,310 --> 00:06:55,610
orbital but the distances the satellite

122
00:06:59,140 --> 00:06:57,320
is moving away from the orbiter are much

123
00:07:02,439 --> 00:06:59,150
smaller than the distance to the center

124
00:07:05,860 --> 00:07:02,449
of the earth if you put a force on these

125
00:07:08,589 --> 00:07:05,870
smaller distances we see that the change

126
00:07:11,140 --> 00:07:08,599
in force is linearly proportional to the

127
00:07:13,810 --> 00:07:11,150
change in distance

128
00:07:16,450 --> 00:07:13,820
we call this difference in the force of

129
00:07:19,300 --> 00:07:16,460
gravity with distance the gravity

130
00:07:22,330 --> 00:07:19,310
gradient force Britons being the

131
00:07:25,120 --> 00:07:22,340
mathematical term for difference

132
00:07:28,990 --> 00:07:25,130
when the tether length doubles the

133
00:07:33,320 --> 00:07:31,129
now we have enough information to

134
00:07:36,640 --> 00:07:33,330
understand why the tether reels out and

135
00:07:39,230 --> 00:07:36,650
stays out so let's put it all together

136
00:07:41,959 --> 00:07:39,240
the acceleration caused by the Earth's

137
00:07:42,890 --> 00:07:41,969
gravity is greater for objects closer to

138
00:07:45,050 --> 00:07:42,900

the Earth's center

139
00:07:47,240 --> 00:07:45,060
this means the orbiter is trying to

140
00:07:49,309 --> 00:07:47,250
accelerate towards the Earth faster than

141
00:07:52,189 --> 00:07:49,319
the satellite this extra acceleration

142
00:07:55,040 --> 00:07:52,199
causes the orbiter to want to fall away

143
00:07:56,890 --> 00:07:55,050
from the satellite creating a stretching

144
00:07:59,179 --> 00:07:56,900
force along the length of the tether and

145
00:08:01,610 --> 00:07:59,189
that's the force that keeps the tether

146
00:08:04,580 --> 00:08:01,620
taut and makes the tethered satellite go

147
00:08:06,439 --> 00:08:04,590
up but how can gravity make something go

148
00:08:07,809 --> 00:08:06,449
up doesn't that violate the law of

149
00:08:10,010 --> 00:08:07,819
conservation of energy

150
00:08:13,249 --> 00:08:10,020
could we be getting something for

151
00:08:15,080 --> 00:08:13,259
nothing to understand how gravity can

152
00:08:17,240 --> 00:08:15,090
make something go up we need to go a

153
00:08:21,019 --> 00:08:17,250
little deeper into dynamics and look at

154
00:08:23,480 --> 00:08:21,029
the concept of center of mass the center

155
00:08:25,640 --> 00:08:23,490
of mass is the point in a system where

156
00:08:28,519 --> 00:08:25,650
the system is evenly distributed and in

157
00:08:30,890 --> 00:08:28,529
balance balance or equilibrium is

158
00:08:33,680 --> 00:08:30,900
important because it means the system is

159
00:08:36,560 --> 00:08:33,690
stable we're all in the same orbit

160
00:08:39,620 --> 00:08:36,570
around the Earth Jeff the orbiter and

161
00:08:42,319 --> 00:08:39,630
these two apples the center of mass

162
00:08:44,209 --> 00:08:42,329
between two objects such as these apples

163
00:08:47,000 --> 00:08:44,219

doesn't change just because they're in

164
00:08:49,790 --> 00:08:47,010
orbit their center of mass is between

165
00:08:52,250 --> 00:08:49,800
them here when I start them spinning

166
00:08:55,220 --> 00:08:52,260
their center of mass continues to be in

167
00:08:57,110 --> 00:08:55,230
the same place if I cut the string so

168
00:08:59,930 --> 00:08:57,120
the apples are attached by the longer

169
00:09:02,389 --> 00:08:59,940
string the center of mass is still in

170
00:09:05,269 --> 00:09:02,399
the same place inside the orbiter which

171
00:09:07,310 --> 00:09:05,279
means in the same orbit what does this

172
00:09:10,220 --> 00:09:07,320
have to do with the orbiter and tethered

173
00:09:12,500 --> 00:09:10,230
satellite when the tethered satellite is

174
00:09:15,650 --> 00:09:12,510
in the orbiters cargo bay the center of

175
00:09:17,630 --> 00:09:15,660
mass is inside the orbiter when we

176
00:09:19,750 --> 00:09:17,640
deploy the satellite do you think the

177
00:09:23,090 --> 00:09:19,760
orbit of the center of mass changes if

178
00:09:25,600 --> 00:09:23,100
it did then we would be violating the

179
00:09:29,449 --> 00:09:25,610
law of the conservation of energy

180
00:09:31,519 --> 00:09:29,459
however like the apples the orbit of the

181
00:09:33,680 --> 00:09:31,529
shuttle satellite system doesn't change

182
00:09:36,410 --> 00:09:33,690
because no external force has been

183
00:09:38,510 --> 00:09:36,420
applied to the system but the positions

184
00:09:39,410 --> 00:09:38,520
of the orbiter and satellite do change

185
00:09:41,660 --> 00:09:39,420
to keep this

186
00:09:43,730 --> 00:09:41,670
systems center of mass in the same orbit

187
00:09:46,910 --> 00:09:43,740
and continue its stable equilibrium

188
00:09:52,310 --> 00:09:46,920

around the earth let's look at that

189
00:09:55,130 --> 00:09:52,320
concept in action on the ground to make

190
00:09:59,570 --> 00:09:55,140
a seesaw balance one person sits in the

191
00:10:01,610 --> 00:09:59,580
middle if we add another person the one

192
00:10:09,110 --> 00:10:01,620
in the middle has to move to keep the

193
00:10:15,480 --> 00:10:11,610
it's the same for our tethered system

194
00:10:17,699 --> 00:10:15,490
when the satellite is extended like the

195
00:10:21,480 --> 00:10:17,709
heavier person on the seesaw the orbiter

196
00:10:23,370 --> 00:10:21,490
stays closer to the center of mass let's

197
00:10:25,590 --> 00:10:23,380
see how much the one hundred thousand

198
00:10:27,749 --> 00:10:25,600
kilogram orbiter moves away from the

199
00:10:29,939 --> 00:10:27,759
center of mass when the five hundred

200
00:10:32,850 --> 00:10:29,949
kilogram satellite is deployed 20

201
00:10:36,059 --> 00:10:32,860
kilometers you could work this problem

202
00:10:38,670 --> 00:10:36,069
out for yourselves because the orbiter

203
00:10:40,470 --> 00:10:38,680
is more massive it moves only about a

204
00:10:43,490 --> 00:10:40,480
hundred meters away from the center of

205
00:10:47,129 --> 00:10:43,500
mass while the satellite moves away

206
00:10:49,259 --> 00:10:47,139
almost 20 kilometers and the center of

207
00:10:52,769 --> 00:10:49,269
mass of the system stays in its original

208
00:10:54,660 --> 00:10:52,779
orbit because the orbiter moves so

209
00:10:57,720 --> 00:10:54,670
little it almost seems like the

210
00:11:00,749 --> 00:10:57,730
satellite alone is moving up but now we

211
00:11:03,870 --> 00:11:00,759
know both objects are moving one up and

212
00:11:06,180 --> 00:11:03,880
one down once you understand this

213
00:11:09,329 --> 00:11:06,190

principle you can also see this

214
00:11:11,069 --> 00:11:09,339
situation is symmetrical we could just

215
00:11:14,100 --> 00:11:11,079
as easily have made the satellite go

216
00:11:17,730 --> 00:11:14,110
down 20 kilometers in the orbiter go up

217
00:11:23,830 --> 00:11:20,820
here's another way of looking at it

218
00:11:26,170 --> 00:11:23,840
think of a pulley system a heavyweight

219
00:11:29,020 --> 00:11:26,180
moves a little to balance a light weight

220
00:11:31,030 --> 00:11:29,030
that moves a lot the weights can move in

221
00:11:34,150 --> 00:11:31,040
either direction the center of mass

222
00:11:37,420 --> 00:11:34,160
stays constant but in space we don't

223
00:11:39,100 --> 00:11:37,430
need a pulley a tether will do now let's

224
00:11:42,730 --> 00:11:39,110
look at the forces that keep the tether

225
00:11:44,950 --> 00:11:42,740
system stable along a vertical axis when

226
00:11:47,920 --> 00:11:44,960
this toy is punched gravity makes it

227
00:11:50,020 --> 00:11:47,930
return to a vertical position the

228
00:11:53,260 --> 00:11:50,030
tethered system could also be perturbed

229
00:11:55,450 --> 00:11:53,270
off the vertical axis without any

230
00:11:58,330 --> 00:11:55,460
restoring force the system would rotate

231
00:12:00,970 --> 00:11:58,340
like these tethered apples but the

232
00:12:04,360 --> 00:12:00,980
tethered system stable equilibrium keeps

233
00:12:06,250 --> 00:12:04,370
it aligned along a vertical axis what

234
00:12:08,980 --> 00:12:06,260
causes the tethered system stable

235
00:12:12,160 --> 00:12:08,990
equilibrium and space well once again

236
00:12:18,810 --> 00:12:12,170
gravity is at work you see gravity pulls

237
00:12:23,430 --> 00:12:21,360
the pull on the satellite at the upper

238
00:12:26,010 --> 00:12:23,440

end of the tether makes the system want

239
00:12:28,260 --> 00:12:26,020
to depart from the vertical while a pole

240
00:12:31,410 --> 00:12:28,270
on the orbiter at the lower end makes

241
00:12:34,410 --> 00:12:31,420
the system return do you remember the

242
00:12:36,990 --> 00:12:34,420
gravity gradient the end closest to the

243
00:12:39,360 --> 00:12:37,000
earth feels the greatest acceleration so

244
00:12:42,900 --> 00:12:39,370
the system feels a net torque and the

245
00:12:44,760 --> 00:12:42,910
tether returns to the vertical it

246
00:12:46,710 --> 00:12:44,770
doesn't matter if the mass is at the end

247
00:12:48,660 --> 00:12:46,720
of the system are equal or not the

248
00:12:51,630 --> 00:12:48,670
gravity gradient is stabilizing the

249
00:12:53,340 --> 00:12:51,640
system but gravity gradient is only part

250
00:12:56,250 --> 00:12:53,350
of the story there's another force at

251
00:12:58,620 --> 00:12:56,260
work remember we saw that there is an

252
00:13:01,080 --> 00:12:58,630
approximate force of 26 Newtons

253
00:13:02,270 --> 00:13:01,090
for the gravity gradient over a 20

254
00:13:05,490 --> 00:13:02,280
kilometer tether

255
00:13:07,890 --> 00:13:05,500
well when the tether is extended 20

256
00:13:11,450 --> 00:13:07,900
kilometers our force measuring device

257
00:13:15,140 --> 00:13:11,460
measures 40 Newtons not 26 Newtons

258
00:13:19,620 --> 00:13:15,150
now where did this extra force come from

259
00:13:22,800 --> 00:13:19,630
here is a clue it's the same force we

260
00:13:25,980 --> 00:13:22,810
feel when we will an object around on a

261
00:13:28,500 --> 00:13:25,990
string and the strain stretches the

262
00:13:31,050 --> 00:13:28,510
faster the speed the harder the force

263
00:13:35,920 --> 00:13:31,060

tries to fling the object away from the

264
00:13:41,360 --> 00:13:39,640
as you have seen gravity helps keep the

265
00:13:43,640 --> 00:13:41,370
Tetra vertical

266
00:13:46,550 --> 00:13:43,650
and you can actually calculate this

267
00:13:50,170 --> 00:13:46,560
expert force and it turns out it's about

268
00:13:52,790 --> 00:13:50,180
half the gravity gradient force a

269
00:13:57,150 --> 00:13:52,800
significant effect

270
00:13:59,820 --> 00:13:57,160
therefore as it orbits the earth it is

271
00:14:03,390 --> 00:13:59,830
actually rotating once per orbit about

272
00:14:07,830 --> 00:14:03,400
its center of mass creating this extra

273
00:14:11,250 --> 00:14:07,840
force that stretches the tether we can

274
00:14:13,830 --> 00:14:11,260
see it in action another way if we have

275
00:14:17,250 --> 00:14:13,840
one of our crews spin a bucket of water

276
00:14:19,650 --> 00:14:17,260
around in a circle the water will stay

277
00:14:23,880 --> 00:14:19,660
inside a bucket as long as the motion

278
00:14:27,480 --> 00:14:23,890
continues stop the motion the force

279
00:14:30,750 --> 00:14:27,490
disappears and the water obeys the law

280
00:14:32,790 --> 00:14:30,760
of gravitational attraction like the

281
00:14:34,860 --> 00:14:32,800
gravity gradient force it is also

282
00:14:37,560 --> 00:14:34,870
proportional to the length of the tether

283
00:14:39,740 --> 00:14:37,570
as long as the rate of rotation stays

284
00:14:46,650 --> 00:14:39,750
constant

285
00:14:48,930 --> 00:14:46,660
assumed that the tether remains at a

286
00:14:53,370 --> 00:14:48,940
constant length and this is not always

287
00:14:55,560 --> 00:14:53,380
the case when we lengthened or shortened

288
00:14:57,810 --> 00:14:55,570

the tether another physics principle

289
00:15:02,310 --> 00:14:57,820
that you've heard of comes into play and

290
00:15:05,430 --> 00:15:02,320
that angular momentum you see it here in

291
00:15:07,950 --> 00:15:05,440
the motion of the skater angular

292
00:15:10,880 --> 00:15:07,960
momentum is the product of an object's

293
00:15:16,440 --> 00:15:10,890
rotational inertia and angular velocity

294
00:15:18,390 --> 00:15:16,450
about a particular axis when the object

295
00:15:21,180 --> 00:15:18,400
changes its mass distribution the

296
00:15:25,530 --> 00:15:21,190
angular momentum stays the same but the

297
00:15:28,860 --> 00:15:25,540
rotation rate changes we call this the

298
00:15:30,630 --> 00:15:28,870
conservation of angular momentum and you

299
00:15:35,310 --> 00:15:30,640
can see for yourself how this principle

300
00:15:37,890 --> 00:15:35,320
works stand on a turntable with your

301
00:15:39,560 --> 00:15:37,900
arms outstretched and weights in your

302
00:15:43,220 --> 00:15:39,570
hands

303
00:15:47,449 --> 00:15:43,230
have someone start you spinning now

304
00:15:48,680 --> 00:15:47,459
bring your arms in you speed up that's

305
00:15:50,480 --> 00:15:48,690
because the more the mass is

306
00:15:55,040 --> 00:15:50,490
concentrated towards the center of mass

307
00:15:57,379 --> 00:15:55,050
the faster the mass spins now let's see

308
00:16:01,970 --> 00:15:57,389
how this part of physics relates to our

309
00:16:04,280 --> 00:16:01,980
spaceship and the data satellite when

310
00:16:06,559 --> 00:16:04,290
the tether is pulled in the rotating

311
00:16:10,249 --> 00:16:06,569
mass of the system is concentrated into

312
00:16:13,490 --> 00:16:10,259
a smaller area and the system tries to

313
00:16:15,680 --> 00:16:13,500

speed up just like the skater when the

314
00:16:18,079 --> 00:16:15,690
tether is let out the mass is

315
00:16:20,990 --> 00:16:18,089
distributed in a bigger area and the

316
00:16:22,850 --> 00:16:21,000
orbiter and tether system slow down just

317
00:16:25,460 --> 00:16:22,860
like the students slow down

318
00:16:27,290 --> 00:16:25,470
when she extended her arms in the

319
00:16:30,379 --> 00:16:27,300
orbiter we see this from a slightly

320
00:16:34,370 --> 00:16:30,389
different perspective because we are

321
00:16:36,259 --> 00:16:34,380
part of the rotating system remember

322
00:16:38,870 --> 00:16:36,269
during most of the mission for

323
00:16:43,040 --> 00:16:38,880
scientific reasons the orbiter is moving

324
00:16:45,350 --> 00:16:43,050
with the tail forward do you notice how

325
00:16:47,030 --> 00:16:45,360
from our point of view the satellite

326
00:16:50,449 --> 00:16:47,040
moves forward with respect to our

327
00:16:52,540 --> 00:16:50,459
direction of motion and moves backward

328
00:16:57,350 --> 00:16:52,550
with respect to our direction of motion

329
00:17:00,319 --> 00:16:57,360
when it's let out and this is called the

330
00:17:04,220 --> 00:17:00,329
Coriolis effect and it occurs in all

331
00:17:05,870 --> 00:17:04,230
rotating systems as a consequence of the

332
00:17:08,960 --> 00:17:05,880
conservation of angular momentum

333
00:17:14,000 --> 00:17:08,970
it is the tendency of objects in

334
00:17:17,370 --> 00:17:14,010
rotating systems to move in a curve as

335
00:17:23,020 --> 00:17:20,680
we'll try to throw a ball from someone

336
00:17:25,270 --> 00:17:23,030
on one side of a merry-go-round

337
00:17:28,690 --> 00:17:25,280
to someone on the other side of the

338
00:17:31,630 --> 00:17:28,700

merry-go-round as we can see the ball is

339
00:17:34,300 --> 00:17:31,640
thrown in a straight line but not from

340
00:17:38,110 --> 00:17:34,310
this point of view here it appears the

341
00:17:39,880 --> 00:17:38,120
balls trajectory is curving and this is

342
00:17:44,470 --> 00:17:39,890
what makes the satellite move backward

343
00:17:47,110 --> 00:17:44,480
or forward as we reel it out or in the

344
00:17:50,790 --> 00:17:47,120
Coriolis effect is what makes hurricanes

345
00:17:53,980 --> 00:17:50,800
spiral and other weather systems curved

346
00:17:56,410 --> 00:17:53,990
we won't go into the mathematics here

347
00:17:59,740 --> 00:17:56,420
except to say that the larger the tether

348
00:18:01,900 --> 00:17:59,750
reel out or reeling rates the greater

349
00:18:08,650 --> 00:18:01,910
the backward or forward motion of the

350
00:18:10,660 --> 00:18:08,660
satellite from the vertical so let's

351
00:18:14,100 --> 00:18:10,670
review the aspects of tether dynamics

352
00:18:18,370 --> 00:18:14,110
that we've looked at so far gravity

353
00:18:20,560 --> 00:18:18,380
center of mass and angular momentum all

354
00:18:23,620 --> 00:18:20,570
of these concepts are studied in your

355
00:18:25,960 --> 00:18:23,630
first-year physics course yet all of it

356
00:18:30,430 --> 00:18:25,970
is used in a way like nothing you've

357
00:18:35,110 --> 00:18:30,440
ever seen before and there are even more

358
00:18:37,060 --> 00:18:35,120
uses of tether technology on orbit we

359
00:18:40,060 --> 00:18:37,070
found we could use the tether to

360
00:18:42,220 --> 00:18:40,070
generate electricity as the copper cord

361
00:18:43,260 --> 00:18:42,230
tether flew through the Earth's magnetic

362
00:18:46,750 --> 00:18:43,270
field

363
00:18:51,610 --> 00:18:46,760

so the question left is what can we use

364
00:18:54,430 --> 00:18:51,620
this to other technology for we could

365
00:18:56,350 --> 00:18:54,440
use tethers to directly study parts of

366
00:18:59,490 --> 00:18:56,360
the Earth's atmosphere that we can't

367
00:19:01,720 --> 00:18:59,500
reach by any present-day technology

368
00:19:05,200 --> 00:19:01,730
tethers could reduce the need for

369
00:19:08,020 --> 00:19:05,210
chemical fuels in space boosting objects

370
00:19:11,830 --> 00:19:08,030
to stay in orbit and assisting others to

371
00:19:13,510 --> 00:19:11,840
deorbit and engineers could use the open

372
00:19:16,330 --> 00:19:13,520
wind tunnel of the Earth's upper

373
00:19:18,700 --> 00:19:16,340
atmosphere for testing the hypersonic

374
00:19:21,700 --> 00:19:18,710
aerodynamics of reentry vehicles and

375
00:19:24,880 --> 00:19:21,710
aerobraking technology

376
00:19:27,250 --> 00:19:24,890
it's even possible that one day tether

377
00:19:29,380 --> 00:19:27,260
driven electric cable cars will ferry

378
00:19:33,970 --> 00:19:29,390
space travelers from earth to

379
00:19:37,270 --> 00:19:33,980
geostationary orbit what uses of tether