1
00:00:07,510 --> 00:00:03,590
perhaps the most important part of a

2
00:00:10,310 --> 00:00:07,520
space voyage is coming home safely

3
00:00:12,629 --> 00:00:10,320
the spacecraft must survive the extreme

4
00:00:14,310 --> 00:00:12,639
heat and friction of re-entry into the

5
00:00:16,630 --> 00:00:14,320
earth's atmosphere

6
00:00:19,109 --> 00:00:16,640
scientists and engineers create heat

7
00:00:21,830 --> 00:00:19,119
shields to protect the spacecraft

8
00:00:25,429 --> 00:00:21,840
but how do they know it will really work

9
00:00:28,070 --> 00:00:25,439
the answer is the arc jet facility

10
00:00:31,189 --> 00:00:28,080
for decades this laboratory recreated

11
00:00:33,750 --> 00:00:31,199
the heat gases and chemistry experienced

12
00:00:36,310 --> 00:00:33,760
during re-entry giving us the confidence

13
00:00:49,750 --> 00:00:36,320

to fly explore

14
00:00:55,189 --> 00:00:52,790
the arc jet combines heat the proper mix

15
00:00:57,670 --> 00:00:55,199
of gases and the chemistry that occurs

16
00:01:00,229 --> 00:00:57,680
at extreme temperatures to simulate the

17
00:01:02,389 --> 00:01:00,239
flow experienced by spacecraft during

18
00:01:04,789 --> 00:01:02,399
their fiery re-entry through earth's

19
00:01:07,510 --> 00:01:04,799
atmosphere so when you're coming back

20
00:01:08,950 --> 00:01:07,520
from low earth orbit or even the moon

21
00:01:10,390 --> 00:01:08,960
you're coming back at very high

22
00:01:12,149 --> 00:01:10,400
velocities

23
00:01:13,270 --> 00:01:12,159
and so from coming back from lower thor

24
00:01:14,789 --> 00:01:13,280
but you're on the order of seven

25
00:01:17,030 --> 00:01:14,799
kilometers a second

26
00:01:19,350 --> 00:01:17,040
uh from the moon you're coming back

27
00:01:22,630 --> 00:01:19,360
about 11 kilometers per second that's

28
00:01:23,590 --> 00:01:22,640
really fast and so when those vehicles

29
00:01:25,990 --> 00:01:23,600
actually

30
00:01:27,429 --> 00:01:26,000
encounter the atmosphere then they're

31
00:01:29,749 --> 00:01:27,439
just essentially slamming right into

32
00:01:31,749 --> 00:01:29,759
that air and so that creates a shock

33
00:01:33,830 --> 00:01:31,759
wave around the vehicle

34
00:01:35,749 --> 00:01:33,840
and right behind that shock that kinetic

35
00:01:38,469 --> 00:01:35,759
energy associated with the reentry is

36
00:01:41,429 --> 00:01:38,479
converted to chemical energy you know so

37
00:01:44,469 --> 00:01:41,439
you take the the basic air it's mostly

38
00:01:47,270 --> 00:01:44,479

nitrogen about 77 nitrogen about 23

39
00:01:48,950 --> 00:01:47,280
oxygen and so what happens is when you

40
00:01:50,789 --> 00:01:48,960
go through that conversion process going

41
00:01:52,069 --> 00:01:50,799
to kinetic to chemical energy what

42
00:01:55,109 --> 00:01:52,079
you're doing is you're breaking apart

43
00:01:56,789 --> 00:01:55,119
the molecules and so at first first is

44
00:01:58,950 --> 00:01:56,799
going to go as the oxygen then it's

45
00:02:01,270 --> 00:01:58,960
going to go the nitrogen so as as

46
00:02:03,990 --> 00:02:01,280
opposed to an oxygen molecule or

47
00:02:06,149 --> 00:02:04,000
nitrogen molecule now you'll have atomic

48
00:02:07,749 --> 00:02:06,159
oxygen or atomic nitrogen and atomic

49
00:02:08,869 --> 00:02:07,759
oxygen can be very i'll call it

50
00:02:11,029 --> 00:02:08,879
corrosive

51
00:02:13,110 --> 00:02:11,039
because it really just eats up material

52
00:02:14,949 --> 00:02:13,120
so all that gas on the other side of the

53
00:02:17,110 --> 00:02:14,959
shock on the vehicle side then

54
00:02:19,670 --> 00:02:17,120
encounters the thermal protection system

55
00:02:21,750 --> 00:02:19,680
and so that's how you have to know

56
00:02:23,430 --> 00:02:21,760
well how does that gas affect that

57
00:02:25,510 --> 00:02:23,440
thermal protection system is it going to

58
00:02:27,830 --> 00:02:25,520
protect the vehicle and of course the

59
00:02:29,750 --> 00:02:27,840
only way we know how to simulate that on

60
00:02:32,470 --> 00:02:29,760
the ground is through these arctic

61
00:02:37,430 --> 00:02:34,790
because we do not know how a material

62
00:02:39,350 --> 00:02:37,440
will behave until it gets in these

63
00:02:41,990 --> 00:02:39,360

facilities there's no

64
00:02:44,150 --> 00:02:42,000
analytical equivalent to an arc jet we

65
00:02:46,550 --> 00:02:44,160
have math models and we have tools but

66
00:02:48,830 --> 00:02:46,560
they require arc jet testing to

67
00:02:51,589 --> 00:02:48,840
benchmark them and to provide decor

68
00:02:53,990 --> 00:02:51,599
properties for those tools so there's a

69
00:02:54,790 --> 00:02:54,000
lot of materials that that might perform

70
00:02:56,710 --> 00:02:54,800
well

71
00:02:58,229 --> 00:02:56,720
in a strictly thermal environment such

72
00:03:00,550 --> 00:02:58,239
as blowtorch

73
00:03:02,309 --> 00:03:00,560
but will not perform the same in an arc

74
00:03:04,390 --> 00:03:02,319
jet or in flight because of this

75
00:03:07,589 --> 00:03:04,400
chemistry of the flow field

76
00:03:10,710 --> 00:03:07,599
so the basic operation of the arc jet is

77
00:03:12,309 --> 00:03:10,720
to simulate the re-entry environment

78
00:03:13,990 --> 00:03:12,319
the nuts and bolts of it is you want to

79
00:03:15,190 --> 00:03:14,000
take gas and just take it to a very high

80
00:03:16,390 --> 00:03:15,200
energy level

81
00:03:19,830 --> 00:03:16,400
and

82
00:03:22,070 --> 00:03:19,840
the heater is the workhorse of the arc

83
00:03:25,190 --> 00:03:22,080
jet facility so all the components come

84
00:03:26,550 --> 00:03:25,200
together uh to make the test work with

85
00:03:29,350 --> 00:03:26,560
high pressure water cooling for the

86
00:03:32,229 --> 00:03:29,360
cooling of segments to the

87
00:03:34,229 --> 00:03:32,239
test gas the nitrogen oxygen to the

88
00:03:36,789 --> 00:03:34,239

electrical power and then into the

89
00:03:38,070 --> 00:03:36,799
vacuum system for testing material

90
00:03:39,910 --> 00:03:38,080
okay so when we

91
00:03:40,710 --> 00:03:39,920
receive a model typically the models

92
00:03:42,710 --> 00:03:40,720
come

93
00:03:45,750 --> 00:03:42,720
with thermocouples already attached and

94
00:03:48,550 --> 00:03:45,760
then in the test chamber we have two

95
00:03:51,509 --> 00:03:48,560
hydraulically actuated sting arms so we

96
00:03:54,070 --> 00:03:51,519
would establish our flow field

97
00:04:02,869 --> 00:03:54,080
and then the model is on a sting arm b

98
00:04:07,589 --> 00:04:04,710
and then we rotate it out out of the

99
00:04:09,830 --> 00:04:07,599
flow field so on that sting arm is where

100
00:04:11,589 --> 00:04:09,840
all the data hookups are so we would run

101
00:04:13,429 --> 00:04:11,599
that to

102
00:04:15,589 --> 00:04:13,439
to our data system

103
00:04:16,949 --> 00:04:15,599
during the test we get all kinds of

104
00:04:19,349 --> 00:04:16,959
additional data

105
00:04:21,030 --> 00:04:19,359
we would test these types of ablators

106
00:04:22,230 --> 00:04:21,040
typically up to three thousand four

107
00:04:24,550 --> 00:04:22,240
thousand

108
00:04:25,670 --> 00:04:24,560
degrees fahrenheit even higher

109
00:04:28,070 --> 00:04:25,680
we would test them at very high

110
00:04:29,430 --> 00:04:28,080
temperatures for

111
00:04:31,350 --> 00:04:29,440
different types of trajectories

112
00:04:33,270 --> 00:04:31,360
primarily for the lunar is what gave the

113
00:04:35,430 --> 00:04:33,280

highest types of heating rates and

114
00:04:37,430 --> 00:04:35,440
correspondingly the highest temperatures

115
00:04:38,469 --> 00:04:37,440
of the surface of the model

116
00:04:41,350 --> 00:04:38,479
for a

117
00:04:43,350 --> 00:04:41,360
iss type of re-entry

118
00:04:44,550 --> 00:04:43,360
the heating rates are a lot lower so

119
00:04:45,670 --> 00:04:44,560
we're talking about two thousand three

120
00:04:47,350 --> 00:04:45,680
thousand

121
00:04:49,350 --> 00:04:47,360
degrees but for a lunar type very

122
00:04:51,350 --> 00:04:49,360
ballistic type of re-entry

123
00:04:52,629 --> 00:04:51,360
you're about four thousand degrees even

124
00:04:54,670 --> 00:04:52,639
higher than that

125
00:04:57,590 --> 00:04:54,680
the use of the arc jet began in the

126
00:04:59,670 --> 00:04:57,600
1960s for the apollo program

127
00:05:01,670 --> 00:04:59,680
scientists and engineers needed to test

128
00:05:03,909 --> 00:05:01,680
the heat shield material for the apollo

129
00:05:06,790 --> 00:05:03,919
spacecraft which would be returning to

130
00:05:08,870 --> 00:05:06,800
earth at unprecedented speeds as you

131
00:05:10,790 --> 00:05:08,880
know we had to develop an apollo heat

132
00:05:12,629 --> 00:05:10,800
shield material

133
00:05:15,350 --> 00:05:12,639
and to do that we actually tested

134
00:05:17,430 --> 00:05:15,360
several different ablator materials

135
00:05:18,950 --> 00:05:17,440
from different companies well we did

136
00:05:20,550 --> 00:05:18,960
learn several things that there are

137
00:05:22,310 --> 00:05:20,560
certain ingredients that you can put in

138
00:05:23,430 --> 00:05:22,320

the material that do not enhance its

139
00:05:25,430 --> 00:05:23,440
performance

140
00:05:26,710 --> 00:05:25,440
in fact one of the materials that we

141
00:05:29,590 --> 00:05:26,720
actually tested

142
00:05:31,909 --> 00:05:29,600
a big claim by the company

143
00:05:35,029 --> 00:05:31,919
was the ingredient that they put in it

144
00:05:37,350 --> 00:05:35,039
was what really made it great

145
00:05:38,950 --> 00:05:37,360
we tested that material with their

146
00:05:41,029 --> 00:05:38,960
so-called

147
00:05:43,270 --> 00:05:41,039
magic ingredient

148
00:05:44,950 --> 00:05:43,280
and we didn't get very good results

149
00:05:46,070 --> 00:05:44,960
however we took the ingredient out of

150
00:05:48,870 --> 00:05:46,080
the material

151
00:05:51,110 --> 00:05:48,880
retested it and it was much better

152
00:05:53,189 --> 00:05:51,120
so that's the facility allows you to

153
00:05:54,710 --> 00:05:53,199
test those things and make judgments on

154
00:05:55,990 --> 00:05:54,720
the material itself

155
00:05:57,830 --> 00:05:56,000
absolutely

156
00:05:59,110 --> 00:05:57,840
the apollo material because of the arc

157
00:06:01,029 --> 00:05:59,120
jet testing

158
00:06:03,830 --> 00:06:01,039
went from a high density material of

159
00:06:06,309 --> 00:06:03,840
around 60 pounds per cubic foot

160
00:06:08,790 --> 00:06:06,319
all the way down to around 32 pounds per

161
00:06:10,230 --> 00:06:08,800
cubic foot by the addition of some

162
00:06:12,950 --> 00:06:10,240
fillers we call them

163
00:06:15,510 --> 00:06:12,960

uh within the material and we still got

164
00:06:17,430 --> 00:06:15,520
really good performance we got

165
00:06:19,510 --> 00:06:17,440
good temperature performance we got good

166
00:06:22,469 --> 00:06:19,520
installation performance and we got the

167
00:06:24,150 --> 00:06:22,479
good surface performance that we wanted

168
00:06:26,950 --> 00:06:24,160
from the ablator itself

169
00:06:28,870 --> 00:06:26,960
so absolutely you can test a material

170
00:06:30,950 --> 00:06:28,880
with various compositions

171
00:06:33,430 --> 00:06:30,960
and make good judgments on how that

172
00:06:34,950 --> 00:06:33,440
composition changes that material

173
00:06:36,550 --> 00:06:34,960
under these conditions of pressure and

174
00:06:39,350 --> 00:06:36,560
temperature

175
00:06:41,510 --> 00:06:39,360
as the apollo program ended the arc jet

176
00:06:43,749 --> 00:06:41,520
was called into service once again to

177
00:06:45,270 --> 00:06:43,759
test the thermal protection system for

178
00:06:47,909 --> 00:06:45,280
the space shuttle

179
00:06:50,710 --> 00:06:47,919
unlike the apollo spacecraft which was a

180
00:06:52,710 --> 00:06:50,720
one-use vehicle the shuttle spacecraft

181
00:06:54,150 --> 00:06:52,720
would be used again and again for

182
00:06:56,629 --> 00:06:54,160
multiple flights

183
00:06:59,270 --> 00:06:56,639
its thermal protection consisted of new

184
00:07:01,510 --> 00:06:59,280
lightweight tiles

185
00:07:04,070 --> 00:07:01,520
and reinforced carbon-carbon shielding

186
00:07:05,830 --> 00:07:04,080
for the nose and wing leading edges

187
00:07:07,510 --> 00:07:05,840
i was a manager on the carbon system

188
00:07:09,990 --> 00:07:07,520

which was a high temperature portion of

189
00:07:11,670 --> 00:07:10,000
the orbiter thermal protection system

190
00:07:13,909 --> 00:07:11,680
and because we needed to go to high

191
00:07:15,270 --> 00:07:13,919
temperatures which was the hottest spot

192
00:07:17,350 --> 00:07:15,280
on the vehicle we could test

193
00:07:19,589 --> 00:07:17,360
temperatures in excess of

194
00:07:21,029 --> 00:07:19,599
3000 degrees fahrenheit on the surface

195
00:07:23,189 --> 00:07:21,039
of the material

196
00:07:27,029 --> 00:07:23,199
which allowed us to develop

197
00:07:28,830 --> 00:07:27,039
performance curves performance analysis

198
00:07:30,950 --> 00:07:28,840
limits of the materials

199
00:07:31,990 --> 00:07:30,960
performance just about anything you want

200
00:07:35,270 --> 00:07:32,000
to know

201
00:07:37,110 --> 00:07:35,280
early on in the carbon program we

202
00:07:39,110 --> 00:07:37,120
uncovered along with some testing done

203
00:07:41,430 --> 00:07:39,120
at ames research center

204
00:07:43,430 --> 00:07:41,440
a phenomenon that we called

205
00:07:45,510 --> 00:07:43,440
oxidation between the coating of the

206
00:07:47,670 --> 00:07:45,520
carbon which was a silicon carbide

207
00:07:49,510 --> 00:07:47,680
coating and the carbon substrate which

208
00:07:51,749 --> 00:07:49,520
is basically carbon

209
00:07:53,830 --> 00:07:51,759
we had what we call pinhole formations

210
00:07:54,710 --> 00:07:53,840
between the interface

211
00:07:56,869 --> 00:07:54,720
which

212
00:08:00,070 --> 00:07:56,879
was not satisfactory because we could

213
00:08:01,990 --> 00:08:00,080

lose the carbon coating system

214
00:08:04,070 --> 00:08:02,000
due to lack of strength between the

215
00:08:05,510 --> 00:08:04,080
coating and the carbon cell and carbide

216
00:08:07,510 --> 00:08:05,520
coating

217
00:08:09,350 --> 00:08:07,520
that was a very important finding

218
00:08:11,749 --> 00:08:09,360
between

219
00:08:14,469 --> 00:08:11,759
ames and johnson space center in arctic

220
00:08:17,189 --> 00:08:14,479
testing as a result of that we developed

221
00:08:20,390 --> 00:08:17,199
a system called the teo system

222
00:08:23,670 --> 00:08:20,400
a tetraethylene silicate which we could

223
00:08:25,510 --> 00:08:23,680
infiltrate into the porosity of the

224
00:08:27,189 --> 00:08:25,520
carbon system

225
00:08:29,110 --> 00:08:27,199
which then protected

226
00:08:30,629 --> 00:08:29,120
this formation of these so-called

227
00:08:33,110 --> 00:08:30,639
pinholes

228
00:08:35,589 --> 00:08:33,120
for decades work continued with the arc

229
00:08:37,750 --> 00:08:35,599
jet in service of the space shuttle both

230
00:08:40,230 --> 00:08:37,760
testing for improvements of the thermal

231
00:08:42,389 --> 00:08:40,240
protection system as well as for

232
00:08:45,670 --> 00:08:42,399
unexpected events

233
00:08:48,310 --> 00:08:45,680
yeah very memorable tests uh for me was

234
00:08:49,829 --> 00:08:48,320
after the columbia accident

235
00:08:52,150 --> 00:08:49,839
obviously

236
00:08:53,670 --> 00:08:52,160
it all hit us very hard

237
00:08:55,590 --> 00:08:53,680
and we immediately came into this

238
00:08:58,230 --> 00:08:55,600

facility to help

239
00:09:00,550 --> 00:08:58,240
uh understand what happened during that

240
00:09:03,030 --> 00:09:00,560
accident at that point in time we knew

241
00:09:05,190 --> 00:09:03,040
that we actually had a hole in the

242
00:09:08,790 --> 00:09:05,200
leading edge of the orbiter and so what

243
00:09:11,670 --> 00:09:08,800
we did is we we put a hole in some

244
00:09:13,350 --> 00:09:11,680
aluminum plates and we put some

245
00:09:15,350 --> 00:09:13,360
big thick cables

246
00:09:17,750 --> 00:09:15,360
behind that and we were trying to do is

247
00:09:19,430 --> 00:09:17,760
trying to understand how the flow could

248
00:09:21,430 --> 00:09:19,440
be ingested through a hole

249
00:09:23,509 --> 00:09:21,440
and then destroy some of the cabling

250
00:09:25,430 --> 00:09:23,519
that controls the vehicle itself

251
00:09:27,350 --> 00:09:25,440
and so we actually set up that process

252
00:09:28,150 --> 00:09:27,360
and actually did the those arctic tests

253
00:09:30,710 --> 00:09:28,160
here

254
00:09:32,230 --> 00:09:30,720
and of cour it helped us get data to

255
00:09:34,310 --> 00:09:32,240
correlate to our models so we could

256
00:09:36,470 --> 00:09:34,320
better describe what happened during the

257
00:09:38,870 --> 00:09:36,480
accident itself

258
00:09:41,990 --> 00:09:38,880
so those are some very important tests

259
00:09:43,829 --> 00:09:42,000
that we did and very quickly and

260
00:09:48,829 --> 00:09:43,839
very important to understanding and all

261
00:09:50,710 --> 00:09:48,839
that is is documented in the cave report

262
00:09:52,230 --> 00:09:50,720
sts-117

263
00:09:54,230 --> 00:09:52,240

where we had a

264
00:09:56,870 --> 00:09:54,240
blanket that was uh

265
00:09:58,870 --> 00:09:56,880
detached partially from uh from the

266
00:10:01,269 --> 00:09:58,880
ohm's pod which is back the back on the

267
00:10:02,790 --> 00:10:01,279
back towards the tail of the orbiter and

268
00:10:04,870 --> 00:10:02,800
we could see it

269
00:10:08,069 --> 00:10:04,880
we were concerned about how to repair it

270
00:10:09,430 --> 00:10:08,079
and so we some innovative folks said hey

271
00:10:12,470 --> 00:10:09,440
we got these

272
00:10:14,310 --> 00:10:12,480
medical staples on board we sent an

273
00:10:16,150 --> 00:10:14,320
astronaut out there and used this staple

274
00:10:18,470 --> 00:10:16,160
gun to stitch this thing back together

275
00:10:20,310 --> 00:10:18,480
but we didn't know is what would happen

276
00:10:22,870 --> 00:10:20,320
with the staples during re-entry would

277
00:10:25,030 --> 00:10:22,880
they just disintegrate and then

278
00:10:26,870 --> 00:10:25,040
and then the repair would be worthless

279
00:10:28,949 --> 00:10:26,880
did that test and that repair worked

280
00:10:30,870 --> 00:10:28,959
beautifully we had camera on it steve

281
00:10:33,430 --> 00:10:30,880
did a good job setting up a camera and

282
00:10:35,990 --> 00:10:33,440
we can see the staples glowing we can

283
00:10:37,269 --> 00:10:36,000
see the pins glowing and they decide yes

284
00:10:38,710 --> 00:10:37,279
do the eva

285
00:10:41,269 --> 00:10:38,720
and it worked great

286
00:10:44,470 --> 00:10:41,279
another mission was sts-118

287
00:10:46,310 --> 00:10:44,480
we saw some ice damage to a tile and so

288
00:10:48,069 --> 00:10:46,320

we said hey we're really concerned about

289
00:10:50,550 --> 00:10:48,079
this is this going to cause a problem

290
00:10:52,710 --> 00:10:50,560
during re-entry so we actually machined

291
00:10:55,590 --> 00:10:52,720
a damage into a tile we did several

292
00:10:56,949 --> 00:10:55,600
tests so we did those tests convinced

293
00:10:59,269 --> 00:10:56,959
ourselves that we'd be okay during

294
00:11:01,590 --> 00:10:59,279
re-entry and lo and behold the the

295
00:11:04,230 --> 00:11:01,600
vehicle did come back and without any

296
00:11:07,110 --> 00:11:04,240
problems whatsoever

297
00:11:09,590 --> 00:11:07,120
the arc jet proved time and again the

298
00:11:12,710 --> 00:11:09,600
importance of testing materials to see

299
00:11:14,870 --> 00:11:12,720
how they would behave during re-entry

300
00:11:17,750 --> 00:11:14,880
the data gathered and the lessons

301
00:11:20,710 --> 00:11:17,760
learned from the arc jet live on