Description of document: National Aeronautics and Space Administration (NASA) Lessons Learned: Lunar Landing, 2011

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Source of document: FOIA request
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National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

January 12, 2026

Reply to attn. of: Office of Communications
History and Information Services Division

Re: FOIA Tracking Number **26-00032-F-HQ**

This responds to your Freedom of Information Act (FOIA) request to the National Aeronautics and Space Administration (NASA), dated October 25, 2025, and received in this office on October 27, 2025. You seek:

> *A copy of the SLIDES for each of these NESC Academy (NASA Engineering and Safety Center) videos. The SLIDES are locked on the website so they cannot be viewed by the public.*
> *A copy of the SLIDES and VIDEOs for parts 2 and 3 listed in item 12 below.*
>
> *1) Lunar Landing*
> *https://nescacademy.nasa.gov/video/427d8334fa41482797cae5cddf7d71a41d*
>
> *2 and 3) Selected Apollo & Shuttle Lessons Learned ({Parts 1 and Part 2)*
> *https://nescacademy.nasa.gov/video/9edb3c4de48e46d7b66f2a91ace96a171d*
> *https://nescacademy.nasa.gov/video/27784b7aa2ce4c628d77143c86232d621d*
>
> *(4, 5, 6 and 7) Failure Recovery (Parts 1, 2, 3 and 4)*
> *https://nescacademy.nasa.gov/video/9efbd739aeae4da6b8a80b7370ccff051d*
> *https://nescacademy.nasa.gov/video/4e202def3eb943c99e4ba2744676392c1d*
> *https://nescacademy.nasa.gov/video/9965475c1f2649c4a56aad45cbc553ab1d*
> *https://nescacademy.nasa.gov/video/44323a56200341a198d3911002f0eb211d*
>
> *8, 9 and 10) Lessons Learned from Fifty Years of Observing Hardware and Human Behavior, Parts 1, 2 and 3*
> *https://nescacademy.nasa.gov/video/c81ccbfd7909415ea72070bbf1c8e38f1d*
> *https://nescacademy.nasa.gov/video/e84a2cc167244d14ac623358f2e9526a1d*
> *https://nescacademy.nasa.gov/video/79e6fd6fc7544b0ba7525f31ed2d866e1d*
>
> *11) Using TRIZ for Engineering Innovation*

https://nescacademy.nasa.gov/video/a42a19ce39a14cd49dfb669e774812b71d

12) Orion Landing Attenuation: slides for Part 1, Part 2, and Part 3. Copy of the video presentation for Part 2 and Part 3
https://nescacademy.nasa.gov/video/806485bdd20041cda2445409cf5737e21d

In response to your request we conducted a search of NASA's Langley Research Center, Engineering and Safety Center (NESC) using the information from your request. NASA's search began on November 18, 2025 and any records created after this date are not included with this response. That/Those search(es) identified the enclosed records that are responsive to your request. We determined that all **533** pages and 2 videos (Orion Part 2 - 55 minutes, 42 seconds; Orion Part 3 - 47 minutes, 52 seconds) are appropriate for release without excision and copies are enclosed.

Appeal

If you believe this to be an adverse determination, you have the right to appeal my action on your request. Your appeal must be received within 90 days of the date of this response. Please send your appeal to:

Administrator
NASA Headquarters
Executive Secretariat
ATTN: FOIA Appeals
MS 9R17
300 E Street S.W.
Washington, DC 2054

Both the envelope and letter of appeal should be clearly marked, "Appeal under the Freedom of Information Act." You must also include a copy of your initial request, the adverse determination, and any other correspondence with the FOIA office. In order to expedite the appellate process and ensure full consideration of your appeal, your appeal should contain a brief statement of the reasons you believe this initial determination should be reversed. Additional information on submitting an appeal is set forth in the NASA FOIA regulations at 14 C.F.R. § 1206.700.

Assistance and Dispute Resolution Services

If you have any questions, please feel free to contact me at derek.m.moore@nasa.gov. For further assistance and to discuss any aspect of your request you may also contact:

Stephanie Fox
FOIA Public Liaison
Freedom of Information Act Office
NASA Headquarters
300 E Street, S.W., 5P32
Washington D.C. 20546
Phone: 202-358-1553
Email: Stephanie.K.Fox@nasa.gov

Additionally, you may contact the Office of Government Information Services (OGIS) at the National Archives and Records Administration to inquire about the FOIA mediation services it offers. The contact information for OGIS is as follows: Office of Government Information Services, National Archives and Records Administration, 8601 Adelphi Road-OGIS, College Park, Maryland 20740-6001, e-mail at ogis@nara.gov; telephone at 202-741-5770; toll free at 1-877-684-6448; or facsimile at 202-741-5769.

Important: Please note that contacting any agency official including myself, NASA's FOIA Public Liaison, and/or OGIS is not an alternative to filing an administrative appeal and does not stop the 90 day appeal clock.

Sincerely,

Derek Moore

Derek Moore
Government Information Specialist

Lesson 11: Lunar Landing

Objectives

- Identify ways in which Lunar Module (LM) designers dealt with numerous constraints
- Determine what factors led to final LM landing gear configuration
- Determine why, for any lander design, astronauts must be kept in development loop

Lesson 11: Lunar Landing

Dr. George Zupp

Mission Phase

Major Issues for a Successful Lunar Mission

- How do we get to Moon?
  - Transportation architecture
    - Earth orbit rendezvous vs. lunar orbit rendezvous
- What is surface like?
  - Surface bearing strength
  - Dust & landing visibility
- Landing gear system design philosophy
  - Landing stability & energy absorption

Transportation Architecture: Primary Candidates

- Earth orbit rendezvous (EOR)
  - Direct descent to lunar surface & return to Earth
- Lunar orbit rendezvous (LOR)
  - Using Apollo/*Saturn V*, primarily 4-stage vehicle
    - S-I, S-II & S-IV + Lunar Module (LM), Service Module (SM) & Command Module (CM)
  - Orbit around Moon from which lunar landing would be initiated
    - Initially in Lunar orbit would be LM, SM & CM
    - SM & CM would remain in orbit during LM descent
  - LOR architecture selected

Polling the Participants

How did LM designers address concerns that surface of Moon may be covered with 100 ft of dust?

0%	a.	Designed LM that could land in 100 ft of dust
0%	b.	Developed sensors that would abort landing if dust concentrations were too high
0%	c.	Designed based on evidence that dust would not be problem to landing
0%	d.	Added probes to landing gear so lander could land in up to 10 ft of dust

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Answer Now

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Parallel Programs: Early Lunar Probes—Ranger Program

- Early programs provided data, greatly reducing landing site uncertainties
- Ranger program
  - Direct shot at Moon, taking pictures up to time of impact
  - First success was Ranger 7 in summer 1964
  - Closest picture was about 1,000 ft with a resolution of 3 ft
  - Photographs in Mare area indicated surface was fairly flat & free of hazardous boulders

Parallel Programs: Early Lunar Probes—Lunar Orbiter & Surveyor

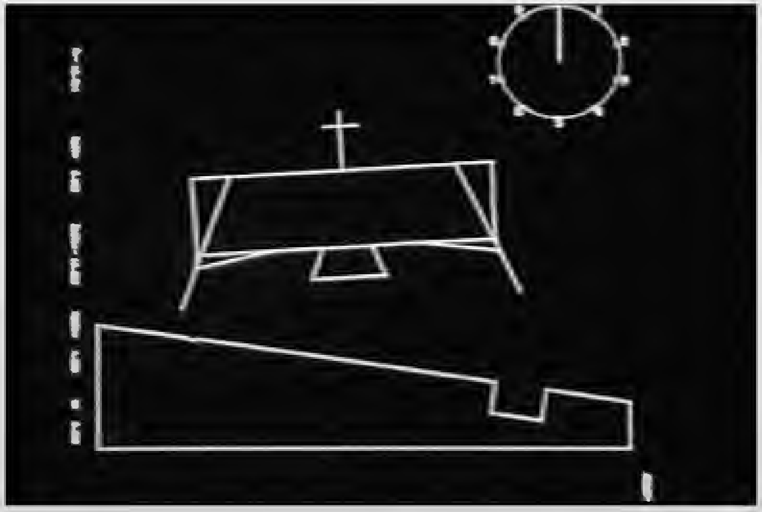
- Lunar Orbiter program
  - Orbit around Moon & photograph potential Apollo landing sites
  - Orbit as low as 28 miles above lunar surface
- Surveyor program
  - First US soft lander with close-up pictures
  - Verified what Ranger program had stated earlier
  - Accurate estimates lunar surface bearing strength & is not covered by thick layer of dust

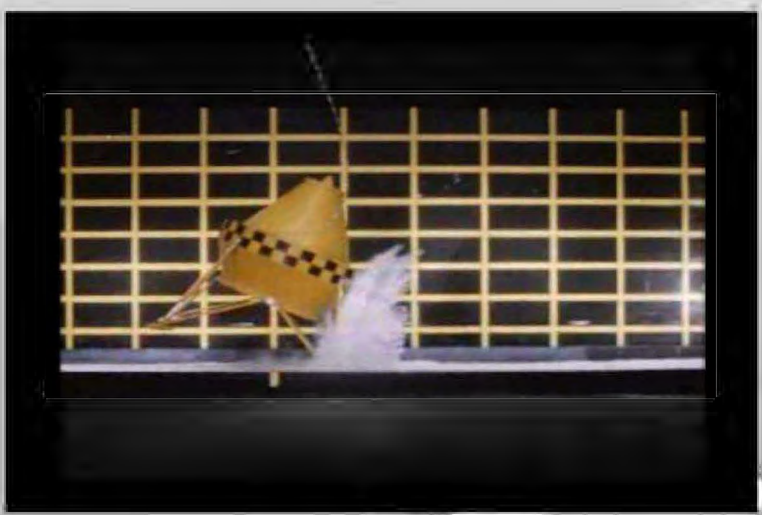
Analysis: Touchdown Dynamics

- From 1963–64, LaRC developed codes for predicting time domain solutions to touchdown dynamics problem
  - 6 DOF rigid body
  - Nonarticulating & nondeforming landing gears
- Grumman Corp. touchdown dynamics computer code
  - 6 DOF rigid body
  - Modeled articulation & deformation of landing gears
- Manned Spacecraft Center code similar to Grumman's
  - Articulating & deformable landing gears
- All these codes were test-verified
  - Used in LM landing dynamic studies & landing gear optimization

Issues with Computer Codes

- Numerical integration
- 2-D models & movies
- Drop test data
  - 1/6 scale model / 1g
  - Full-scale model 1/6g

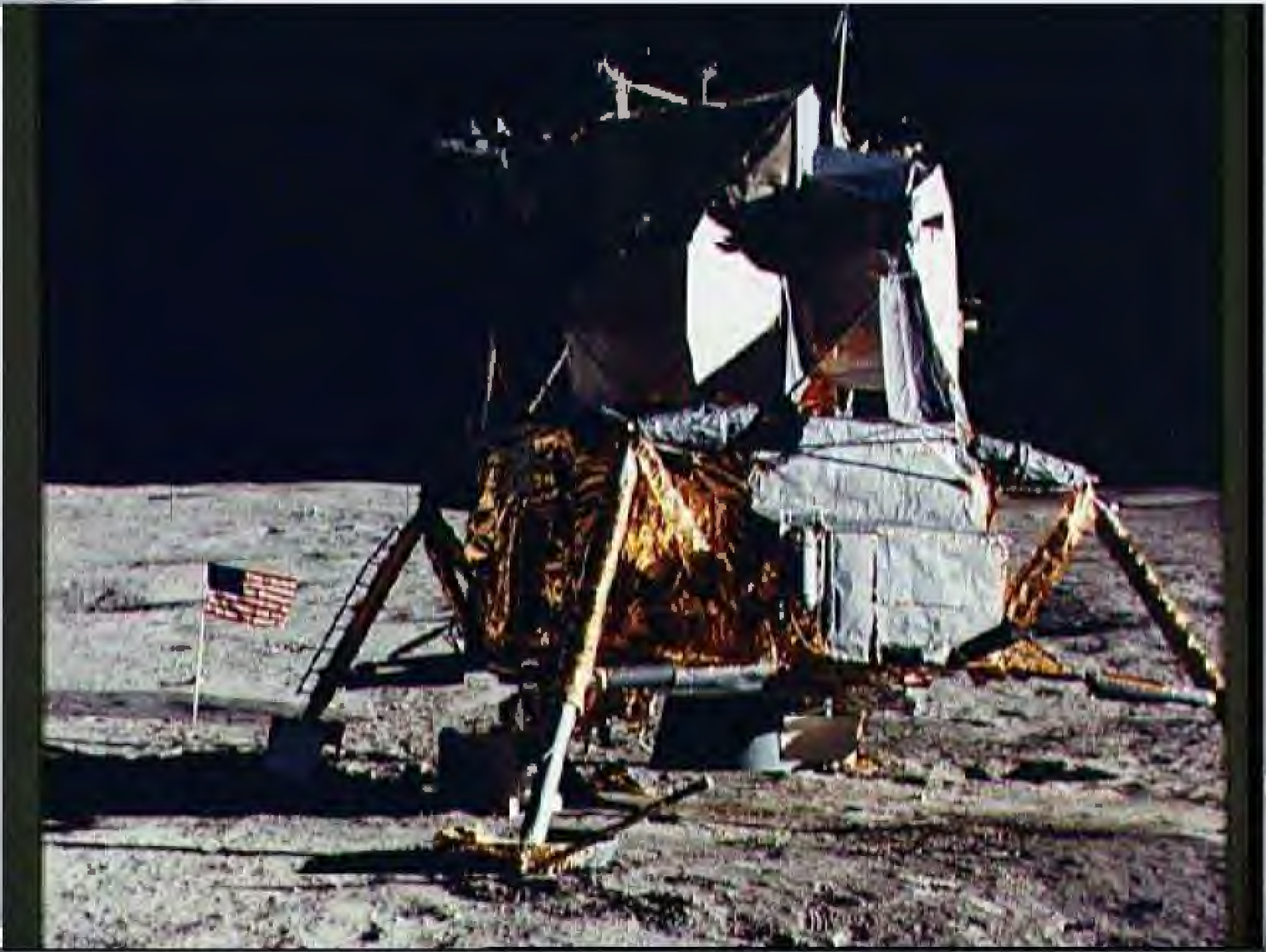




Determining Landing Gear Configuration

- Early studies considered symmetric arrangement of 3, 4 & 5 landing gear legs
  - 4 legs considered optimum configuration
- 2 basic landing gear designs analyzed
  - Inverted tripod
  - Cantilever
- Each design had 3 stroking struts
  - 1 primary
  - 2 secondary
- Cantilever design selected

Lunar Module



Polling the Participants

What was finest resolution image of lunar surface provided by Ranger program?

0% a. 1,000 ft

0% b. 300 ft

0% c. 100 ft

0% d. 3 ft

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21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

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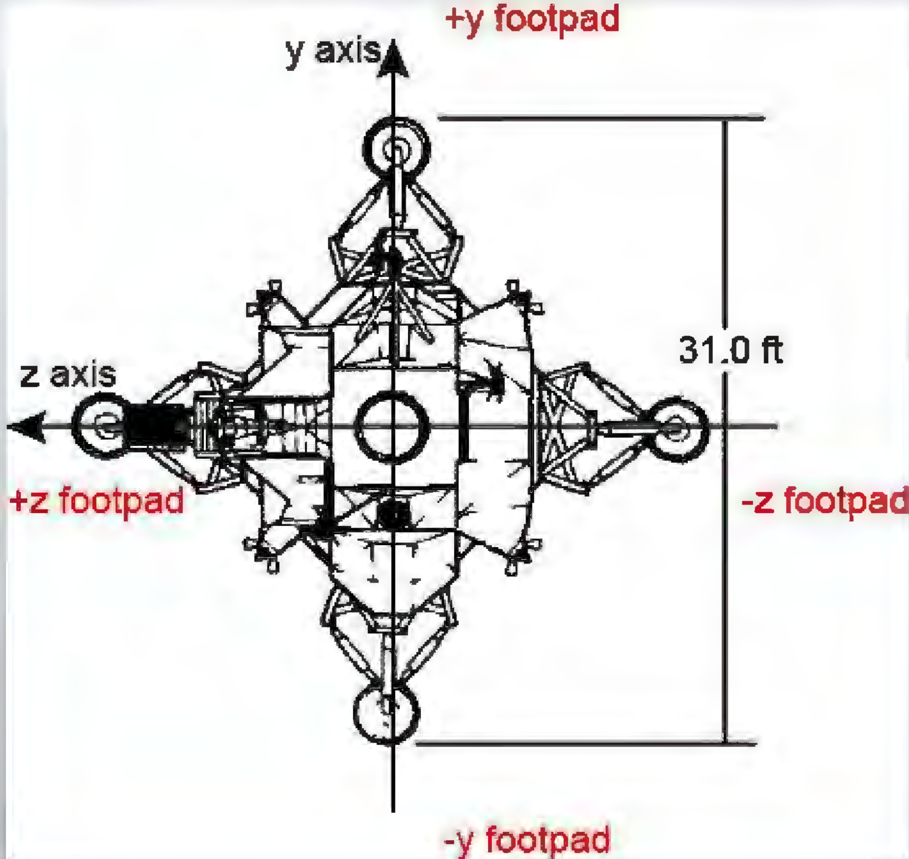
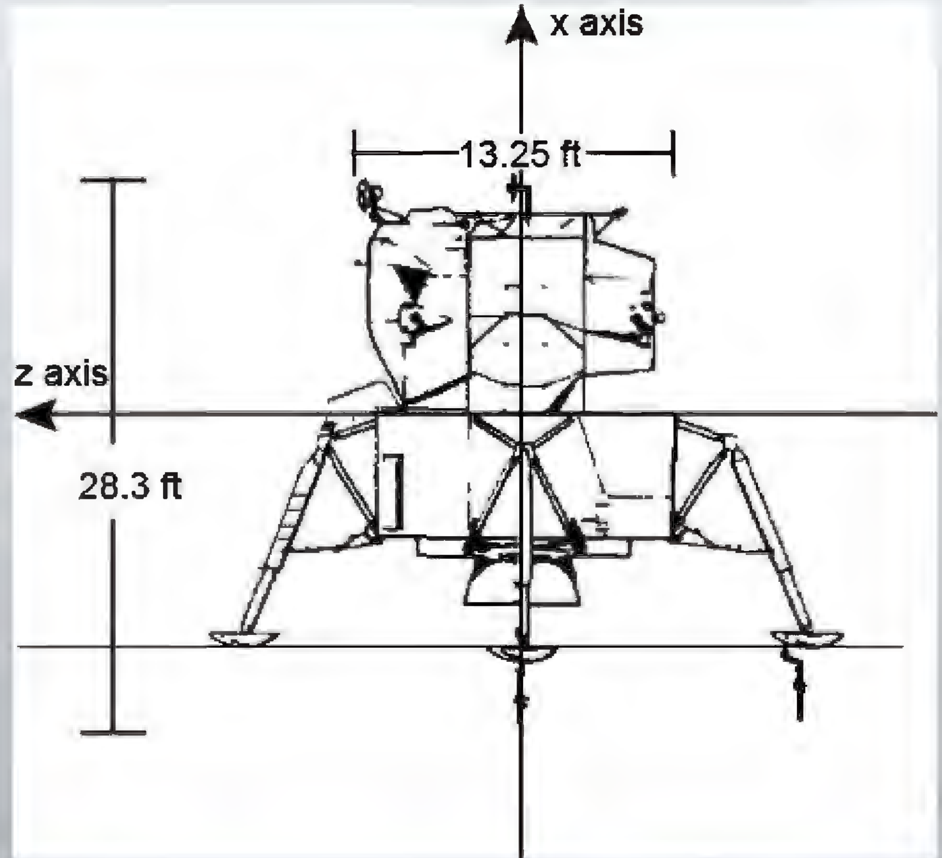
Answer Now

Landing Visibility Issue

- 5.6-ft Lunar Surface Contact Probe was basic to landing gear design
  - Initially probe was attached to each LM footpad
  - Later reduced to 3 probes
- Landing procedure (approximately 12.5 minutes from de-orbit to touchdown)
  - Fly to desired landing point, initiate final descent; probe contacted lunar surface, contact light was illuminated in cabin
  - When probe contact light came on, commander initiated engine shutdown

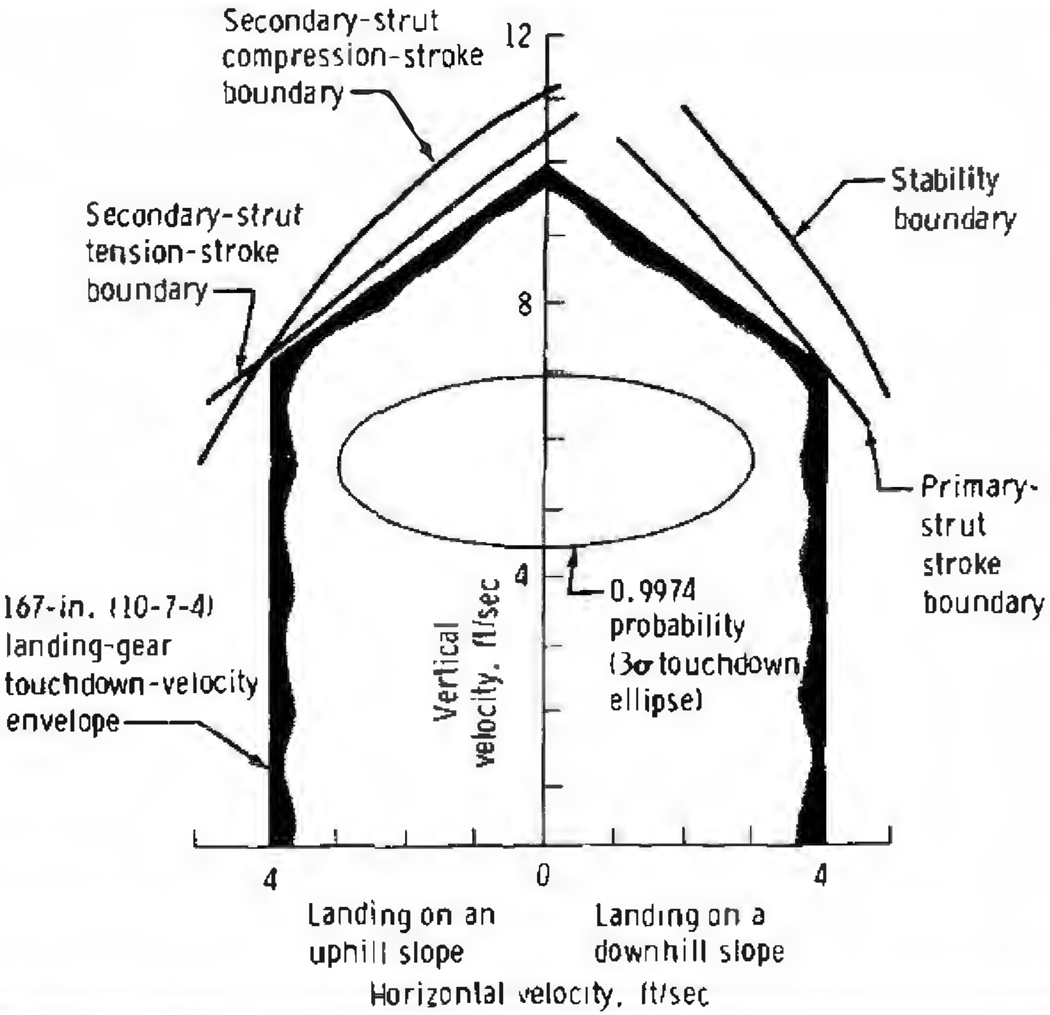
LM with Landing Gear Deployed

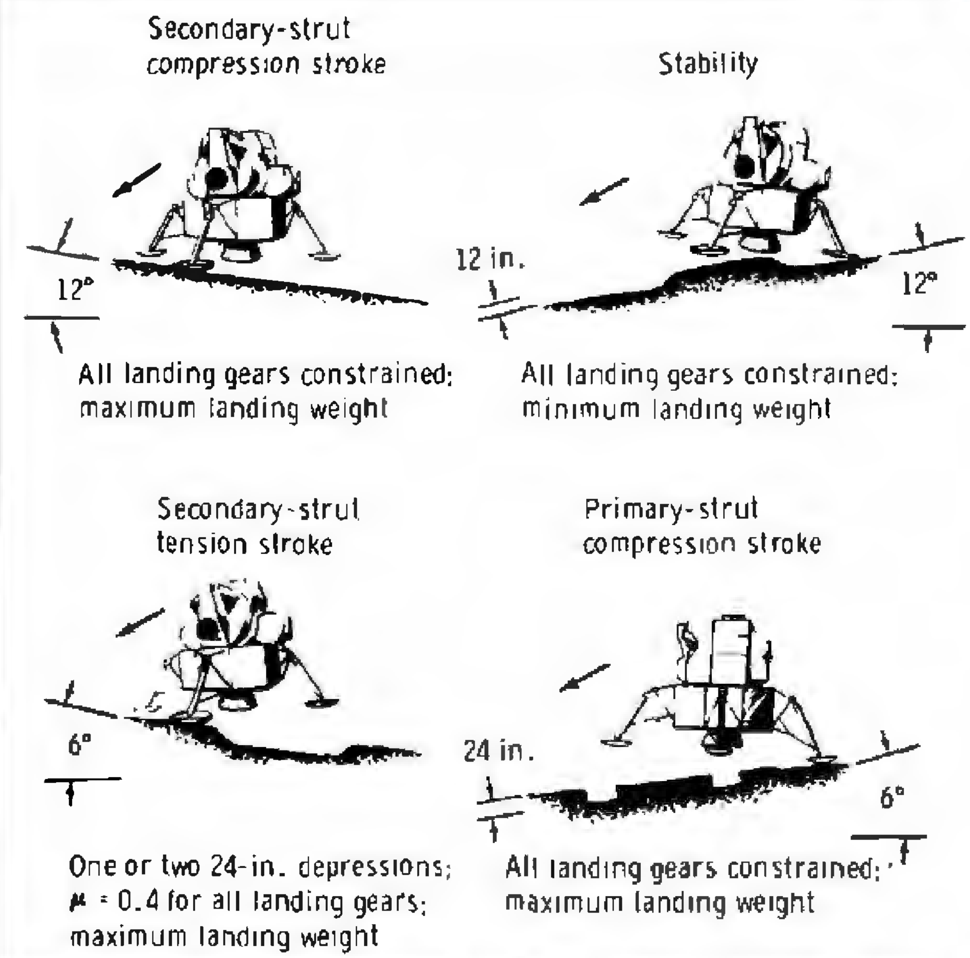




PM 11-8, 11-9

Landing System Performance





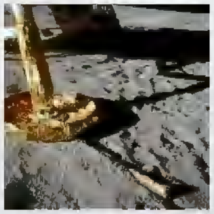
Apollo 11 Lunar Landing

- Landing procedure for *Apollo 11* was not according to design
  - LM commander did not initiate descent engine shut-down until footpads contacted lunar surface
  - This procedure allowed for lower velocity landing than design values
    - Descent engine thrusting during landing gear contact greatly reduced landing stability envelope
  - With lower touchdown velocities, landing system energy absorption margins were high

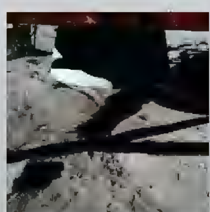
Apollo 11 Touchdown Conditions

- Pitch rate = 0.0100 rad/sec
- Roll rate = 0.0280 rad/sec
- Yaw rate = 0.0108 rad/sec

- Velocity (body x) = −1.80 ft/sec
- Velocity (body y) = −2.20 ft/sec
- Velocity (body z) = 0.10 ft/sec



+ y
footpad



- z
footpad

Apollo 11 Touchdown Dynamics

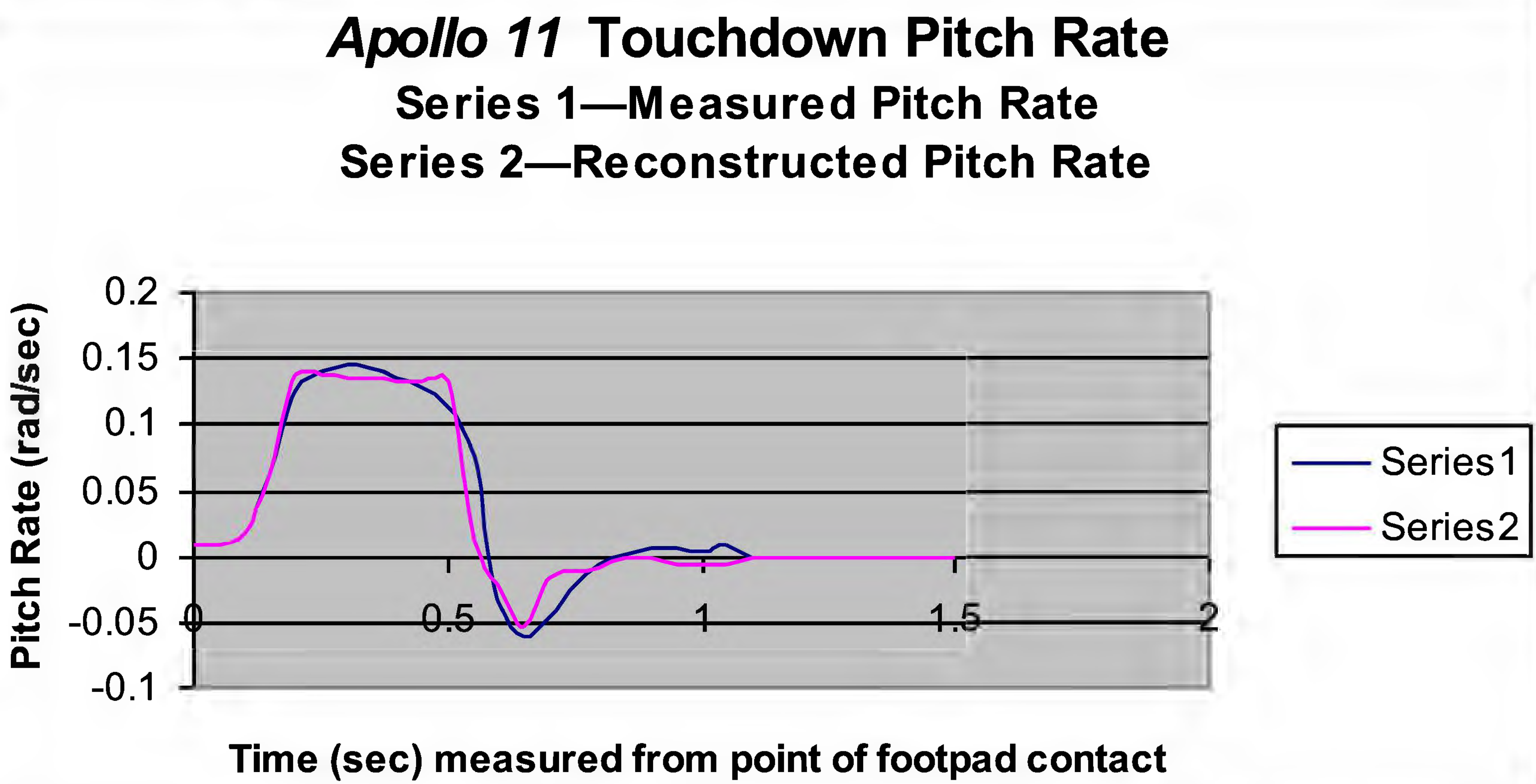
Land gear strut	+Y	+Z	-Y	-Z
Primary strut stroke	0.0	0.0	0.0	0.0
Right secondary -- Comp.	0.0	N/D	0.0	0.0
Strut stroke -------- Ten.	2.7	N/D	3.2	2.5
Left secondary ---- Comp.	0.0	0.0	0.0	0.0
Strut stroke -------- Ten.	0.5	4.0	0.0	N/D

Notes: 1. All strut strokes are in inches & derived from photographs
2. N/D stands for "no data"

Apollo 11 Landing Surface Mechanical Properties

- Lunar surface model
  - Vertical force (Fv) = bearing strength coefficient (Kv) × penetration depth (Zp)
    - Fv = Kv × Zp
  - Horizontal drag force (Fh) = friction coefficient (Mu) × Fv + plowing coefficient (Kp) × skid distance (Sd)
    - Fd = Mu × Fv + Kp × Sd

Apollo 11 Landing Dynamics



Predicted Apollo Landing Gear Strut Strokes

Land gear strut	+Y	+Z	-Y	-Z
Primary strut stroke	0.0	0.0	0.0	0.0
Right secondary -- Comp.	0.0	0.0	0.0	0.0
Strut stroke -------- Ten.	1.8	0.0	1.0	1.5
Left secondary ---- Comp.	0.0	0.0	0.0	0.0
Strut stroke -------- Ten.	0.7	1.8	1.2	0.0

Notes:
1. All strut strokes are in inches
2. Simulation used LM descent engine thrust decay
3. Forces produced by buckling of contact probe were not simulated

Estimates of *Apollo 11* Landing Site Mechanical Properties

Lunar surface parameter	Best estimate	Parameter dispersion
Friction coefficient, Mu	.3	.25–.40
Bearing strength coefficient, Kv	2,000 lb/in.	1,750–2,250 lb/in.
Bearing strength normalized to a footpad bearing area of 380 in^2	5.3 psi/in.	4.6–5.9 psi/in.
Plowing coefficient, Kp	100 lb/ft	75–125 lb/ft
Surface slope	4.5°	4.2–4.8°

Lessons Learned

- Pilot in landing system design loop
- Overdesigned on energy absorption
- Underdesigned on stability
- Descent engine thrust tail-off characteristics used to predict landing stability were short (tenths of seconds)
- In reality, tail-off characteristics for LM descent engine were long (seconds)

Lessons Learned (cont.)

- *Apollo 11* landing site surface-bearing strength was on order of 5 psi/in.
  - More than adequate to support LM's weight
- Dust was generated by LM descent engine plume
  - Not detrimental to touchdown performance
- Success—various engineering organizations in role of Apollo subsystem managers had quick access to program management

Summary

- Parallel programs such as Ranger, Lunar Orbiter & Surveyor removed many uncertainties about lunar surface pertaining to a safe landing site
- LM landing system was designed with assumptions:
  - Lunar surface mechanical properties would have adequate bearing strength
  - Dust produced by engine plume would not hamper successful landing
  - A suitable landing site could be located free of large boulders
- Parallel programs proved assumptions were correct