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NASA Engineering & Safety Center

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National Aeronautics and
Space Administration

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- Apollo CM Water Impact
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APOLLO CM WATER IMPACT

- The Apollo Command Module(CM) was designed to perform a variety of functions involved in launching humans to the moon and returning them safely to Earth on parachutes to a water landing.
- The CM loading associated with the hydrodynamic impact was the focus of significant testing and analysis by NASA and the prime contractor.
- Full scale and quarter scale model testing to measure water impact loading
    - ➢ Testing at JSC facility (led by Jerry McCullough)
    - ➢ Testing done at KSC using a portable test device hauled from JSC to KSC (Terry Reese)
    - ➢ Section head, Harold Benson, Branch Chief, John Kiker
- Testing also done with landing rockets concept (Jack Lands)

APOLLO 16 WATER IMPACT

CM WATER IMPACT TEST

CM LAND IMPACT TEST

CM LANDING ROCKETS CONCEPT TEST

CM LAND LANDING RIG AT KSC

QUARTER SCALE WATER IMPACT TESTING

- Conducted water impact testing of a quarter scale CM model
  - ➢ CM heat-shield model was fiberglass
  - ➢ Upper body was solid wood mass simulator
  - ➢ Accelerometers were mounted on the internal side of the heat shield and on the upper CM body to measure impact loading
  - ➢ Testing was done using a large water tank in the MSC (later called JSC) structures test lab in building 13.
  - ➢ For testing, the test article was suspended from a crane with a bomb-rack device used to release the test article. It was released from a specified height
  - ➢ A high-speed camera system was used to measure the heat shield wetted area as a function of elapse impact time.
    - o Gris was painted on the heat shield
    - o Camera view thru a window on the side of the water tank

QUARTER SCALE MODEL

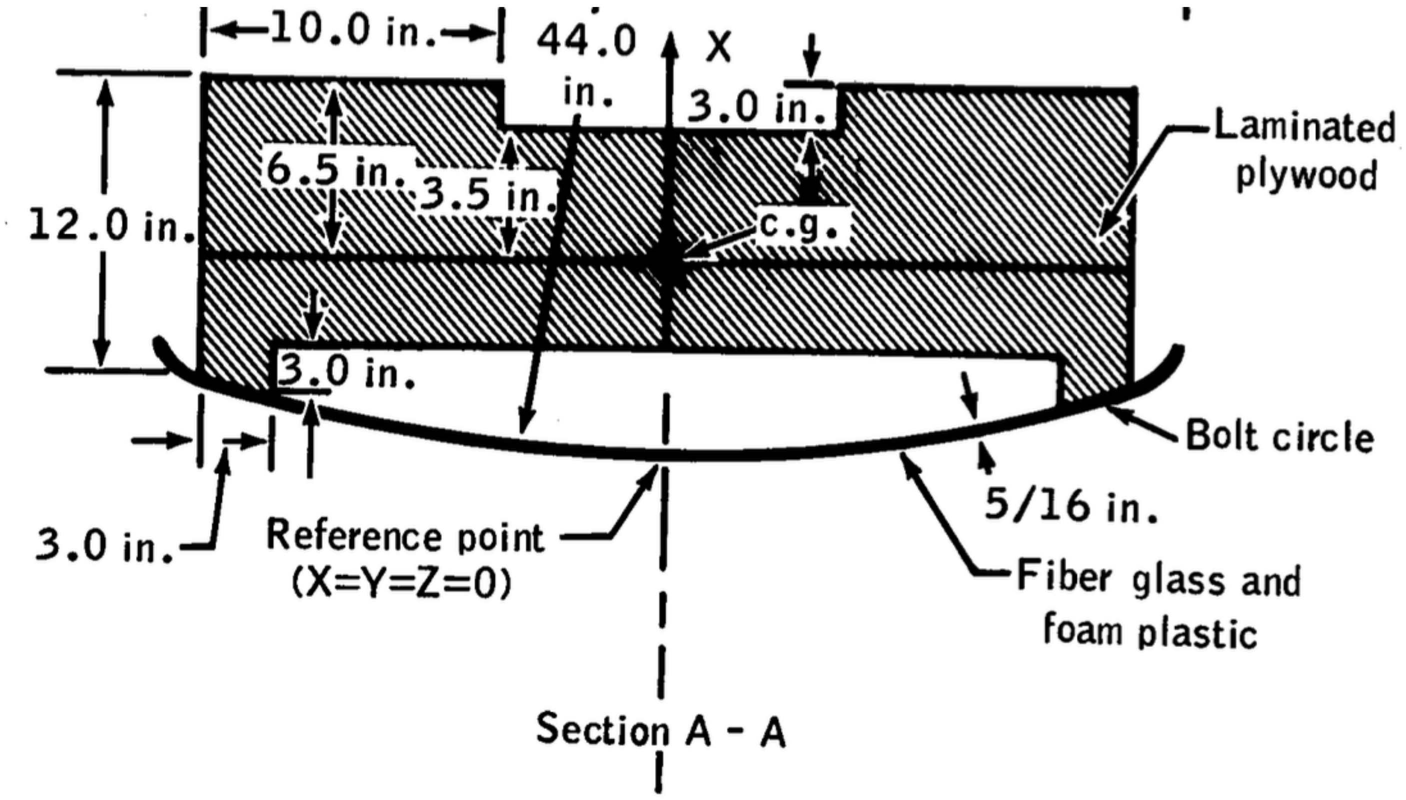
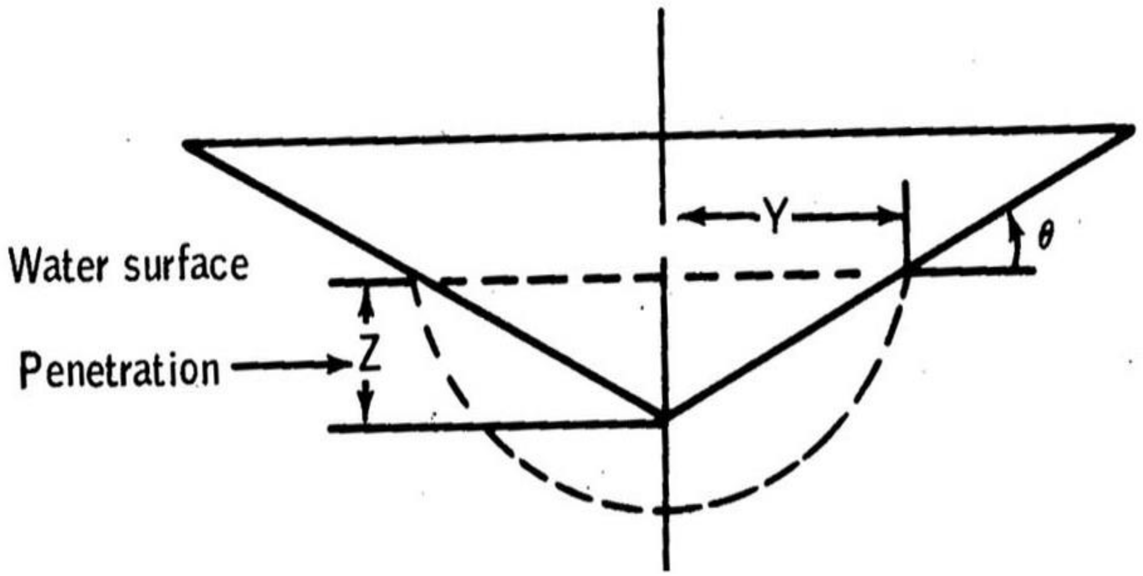


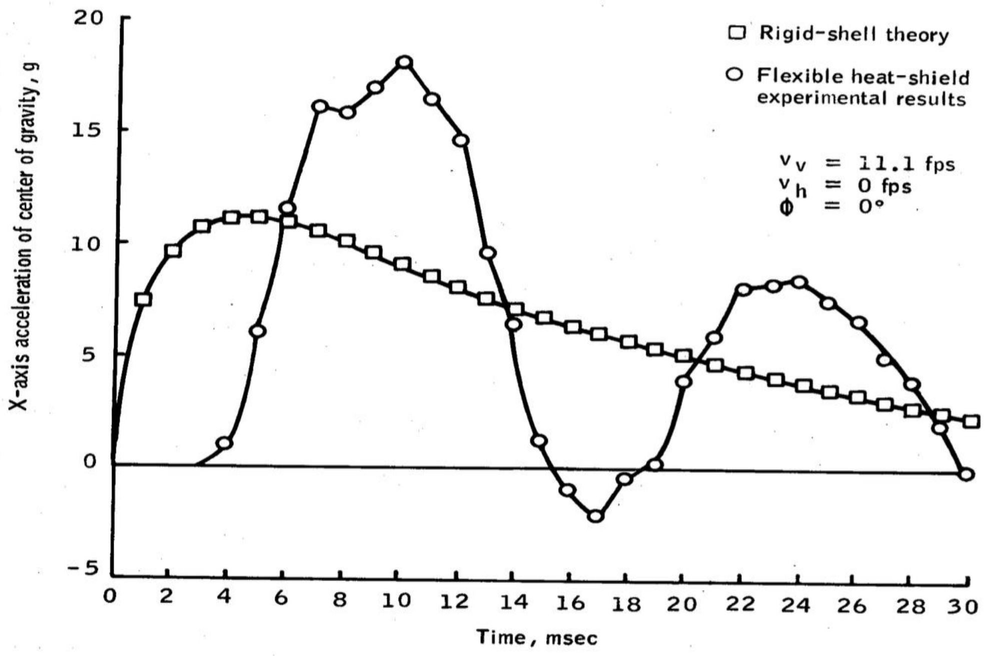
Figure 1. - Model dimensions and characteristics.

WATER IMPACT DATA ANALYSIS

- Basic dynamic analysis of simple spring-mass systems was utilized in the test data assessment/correlation.
- A simple spring-mass model of the heat-shield and upper CM system was used in conjunction with the measured test data to compare measured and predicted impact forces
- This type of modeling was application of basic two-body dynamics principles. Hydrodynamic forces were estimated using a Von Karman wedge impact technique, which includes estimation of the amount of water receiving momentum from the impacting body.
    - Force calculated versus time, as function on impact velocity and depth of penetration into water
    - Similar analyses of seaplane water impact were addressed in the Airplane Aerodynamics text in the Fundamentals of Aerodynamics college course.
    - An adjustment factor was used based on shape of the vehicle

VON KARMAN WEDGE WATER IMPACT AND TEST DATA





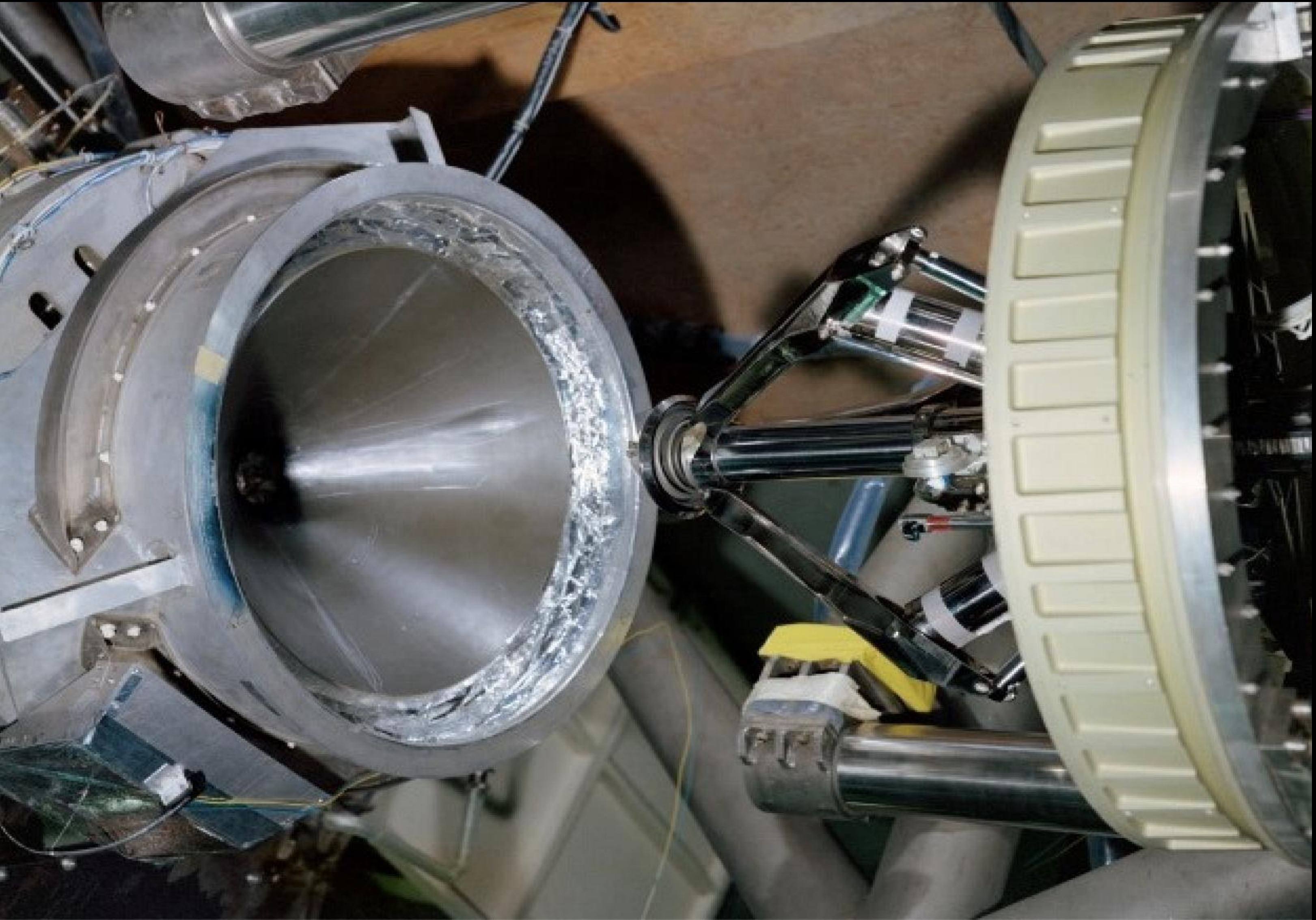
LANDING AND DOCKING SECTION ALUMNI

APOLLO DOCKING

- Analysis and testing of Apollo docking capture performance
- Modeling of docking hardware
  - Probe/cone contact and capture performance
  - GN&C/RCS

LEM IN SIVB

APOLLO DOCKING CAPTURE PERFORMANCE

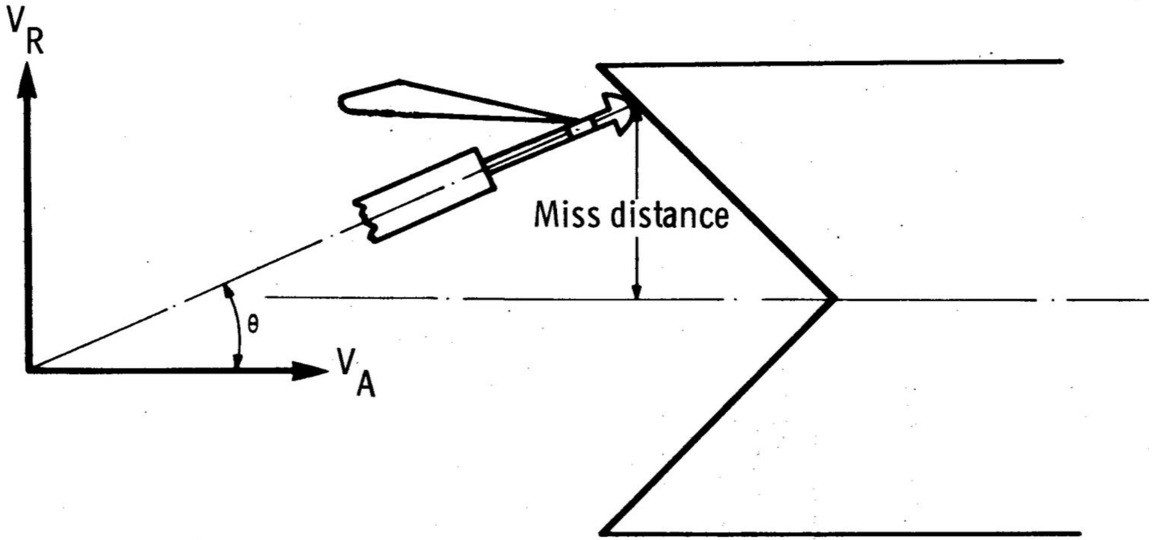


- The Apollo Program utilized a probe-drogue(cone) system to dock and undock the Command Module (CSM) and Lunar Module (LEM) during mission operations.
- The CSM mounted probe system included capture latches in the probe tip to engage the truncated end of the LEM mounted cone to achieve capture.

APOLLO DOCKING SIMULATIONS

- A very detailed mathematical model and computer simulation of the probe/cone docking system was developed by John Schliesing of the JSC Structures and Mechanics Division.
- The simulation modeling utilized Newtonian mechanics and Euler moment equations to simulate motion of the CM and LM.
- The forces in the mechanism were calculated based on kinematics within mechanism components.
  - Relative motions were calculated using knowledge of the state vector of both bodies(CM and LM) and vector analyses.
  - A vector position of any point on the probe surface relative to a point on the drogue surface was used to calculate surface contact and corresponding reaction deflection induced forces, probe stroke, response of the probe dampers, friction, etc.
- This Newton/Euler/vector approach has been used to simulate motion and dynamic/kinematic interaction of multiple bodies and systems in most NASA programs. In college, we did study the Newton/Euler, but on the job training was my first exposure to using position vectors to calculate forces in systems or between moving bodies.
- In conjunction with docking dynamics simulations, views of the standoff-cross docking target from the Crew Optical Alignment System(COAS) were generated. Vector positions of the target area relative to the COAS were calculated at each time step of the docking dynamics simulation. The resulting image were used to generate computer generated movies of the probe/cone docking contact, capture, and retract.

PROBE CONE MODELING



INITIAL CONTACT PARAMETERS

Axial closing velocity V_A, fps	0.1 - 1
Radial velocity V_R, fps	±0.5
Angular misalinement θ, deg	±10
Angular rate $\dot{\theta}$, deg/sec	±1
Miss distance, in.	±12

Figure 1.- Apollo docking criteria for initial contact parameters.

NEWTON AND EULER

VEHICLE EQUATIONS OF MOTION

The equations of motion for the booster and orbiter are obtained from Newton's second law for translation and from Euler's moment equations for rotation.

The elementary equations of translation for each vehicle in component form are

$$\begin{Bmatrix} S\ddot{B}X \\ S\ddot{B}Y \\ S\ddot{B}Z \end{Bmatrix} = \frac{1}{MBT} \begin{Bmatrix} FSMBX \\ FSMBY \\ FSMBZ \end{Bmatrix} \qquad (15)$$

and

$$\begin{Bmatrix} S\ddot{O}X \\ S\ddot{O}Y \\ S\ddot{O}Z \end{Bmatrix} = \frac{1}{MOT} \begin{Bmatrix} FSMOX \\ FSMOY \\ FSMOZ \end{Bmatrix} \qquad (16)$$

where FSMBX, FSMBY, FSMBZ and FSMOX, FSMOY, FSMOZ are the components of the total external forces on each vehicle, respectively.

Euler's moment equations for rotational motion for the booster (refs. 2 and 3) are

$$\begin{Bmatrix} TMBX \\ TMBY \\ TMBZ \end{Bmatrix} = \begin{bmatrix} INRB(I,J) \end{bmatrix} \begin{Bmatrix} \omega\dot{B}X \\ \omega\dot{B}Y \\ \omega\dot{B}Z \end{Bmatrix} + \begin{bmatrix} 0 & -\omega BZ & \omega BY \\ \omega BZ & 0 & -\omega BX \\ -\omega BY & \omega BX & 0 \end{bmatrix} \begin{bmatrix} INRB(I,J) \end{bmatrix} \begin{Bmatrix} \omega BX \\ \omega BY \\ \omega BZ \end{Bmatrix} \qquad (17)$$

where TMBX, TMBY, TMBZ are the components of the total torque vector on the booster c.g.

DOCKING CAPTURE ANALYSIS

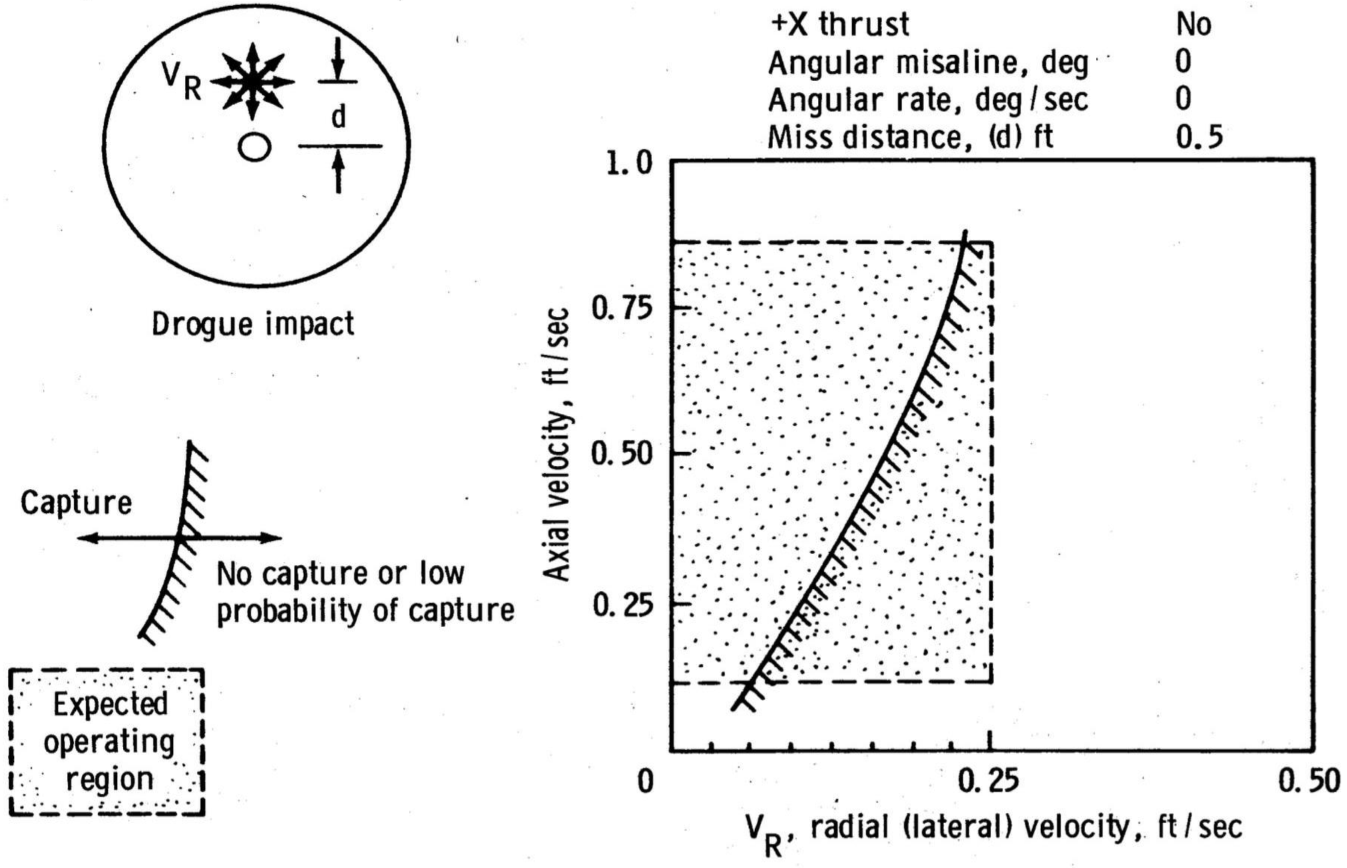


Figure 3.- Mission D, TLD capture boundaries for axial versus radial velocity with no thrust.

CSM LEM COAS ILLUSTRATION

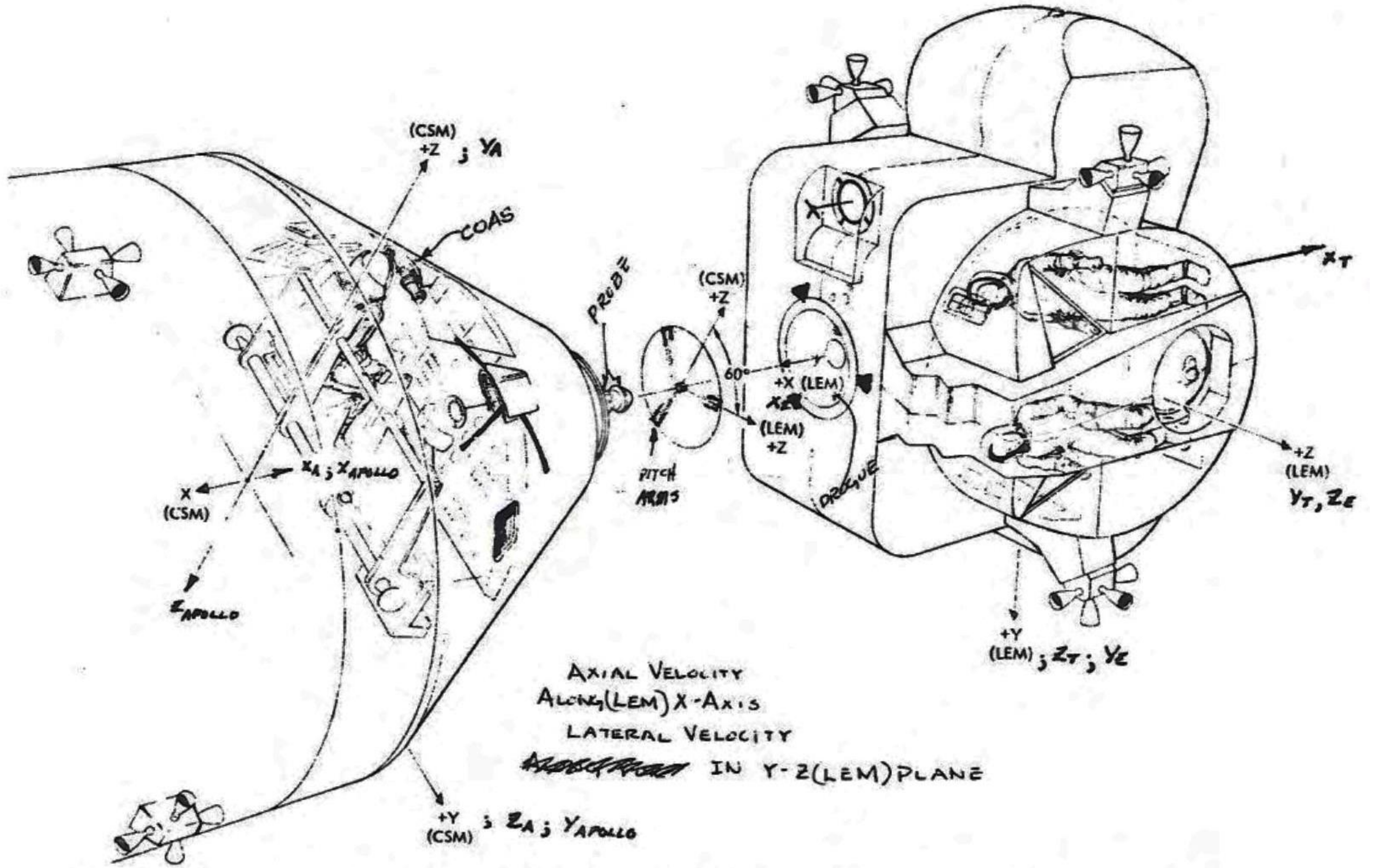


Figure 1 CSM/LEM Docking Roll Orientation, Mathematical Model Coordinate System

DOCKING TARGET ON LEM

APOLLO PARACHUTE INDUCED DYNAMICS

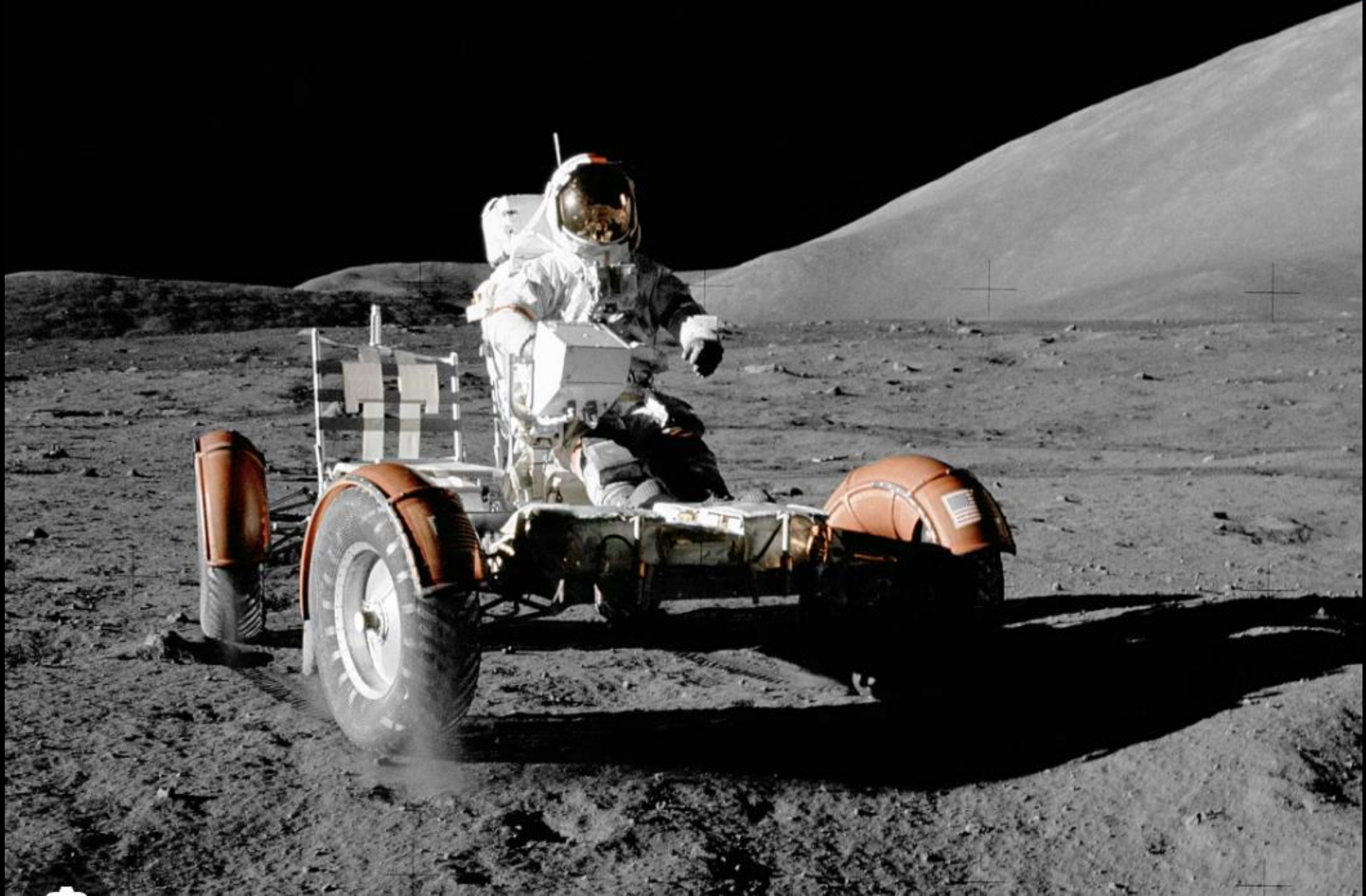
- After parachute deploy during late descent, signification motion of Crew Module could occur
  - ➢CM pitch and yaw
  - ➢CM torsion motion
- Rigid body simulations were developed using Newton/Euler equations
  - ➢Inputs included mass properties, parachute models, attach point geometry
  - ➢Analysis results were compared to GN&C flight data

APOLLO COMMAND MODULE UNDER PARACHUTES

APOLLO LUNAR ROVER STABILITY

- Analyses conducted to assess turnover risk on the Lunar Rover
- Rigid body analyses of turnover risk when turning at high speed

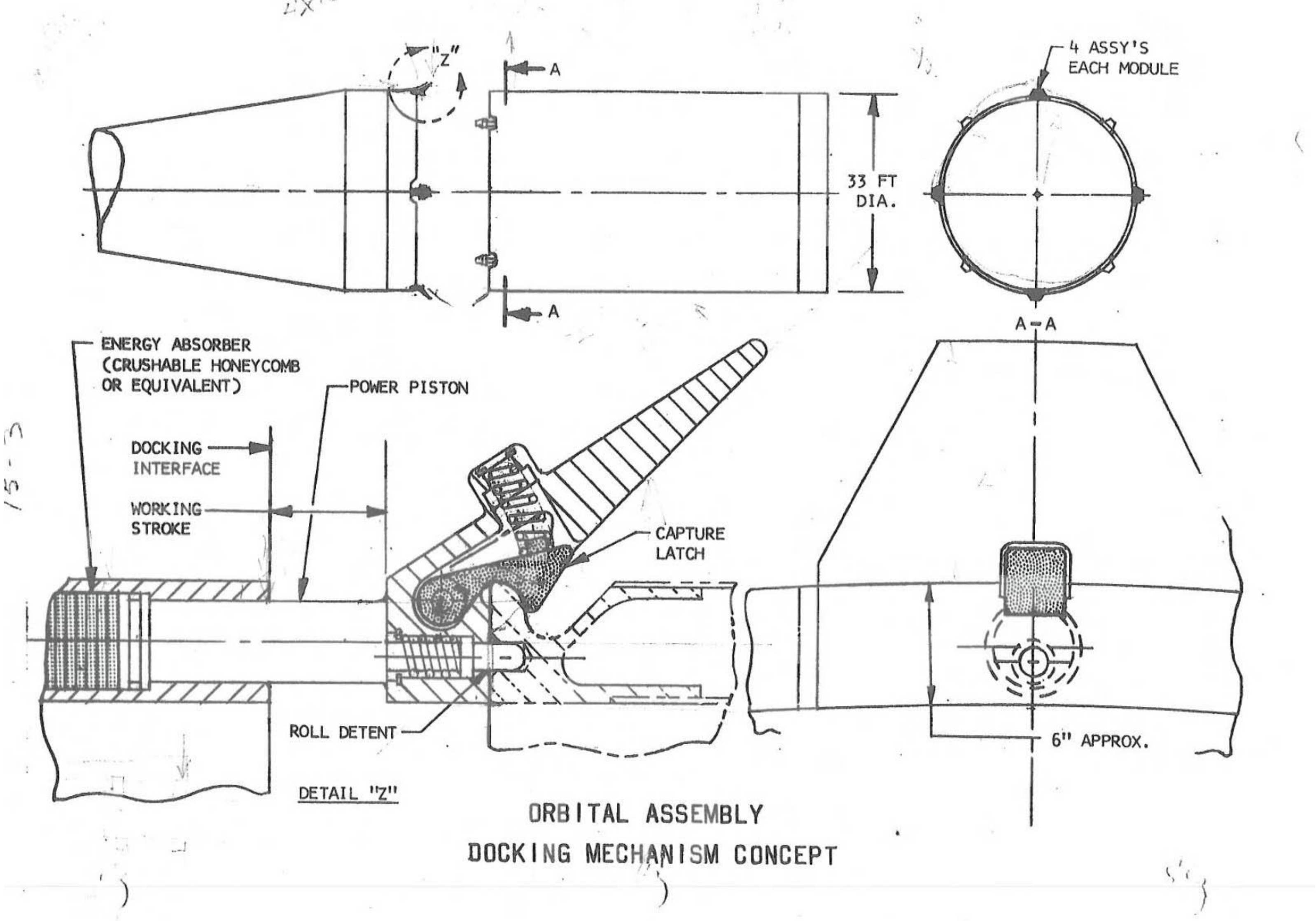
LUNAR ROVER ON MOON



ALTERNATE DOCKING SYSTEM ANALYSIS

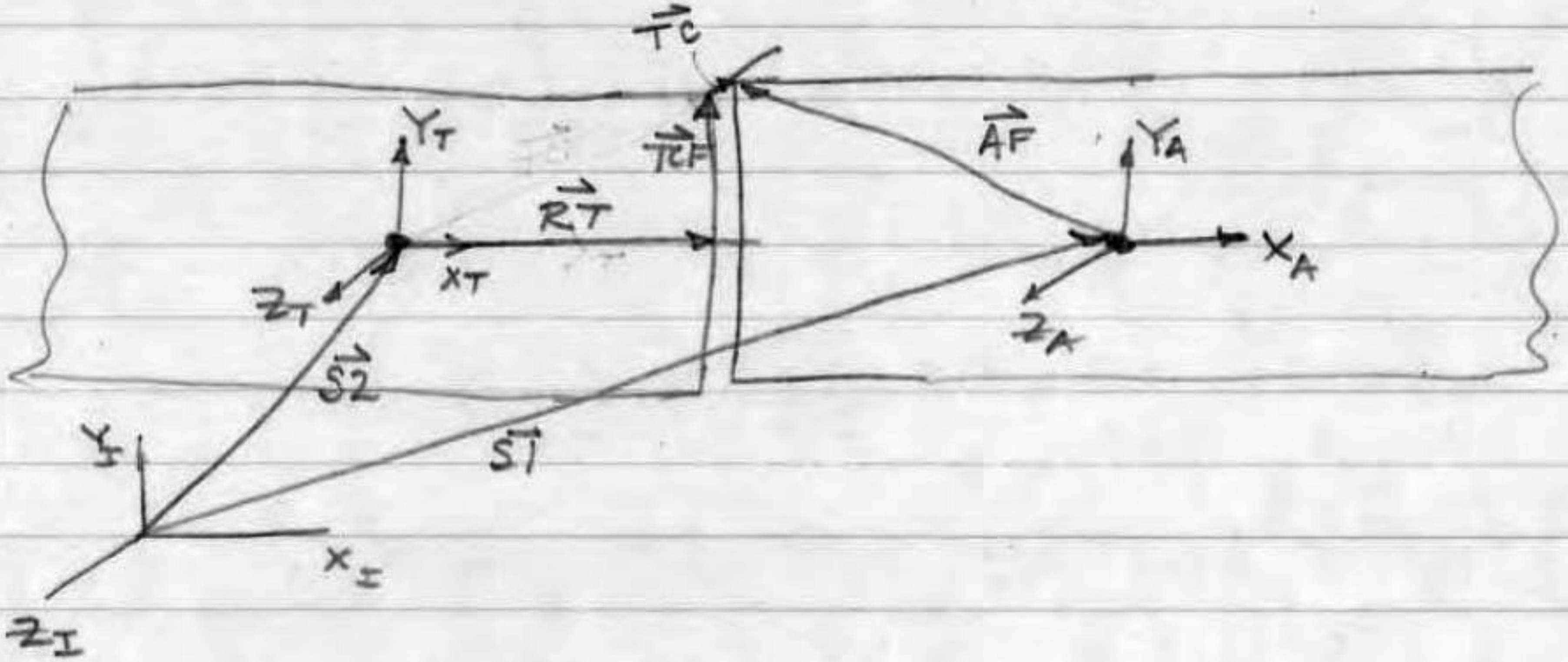
- After conducting docking analyses for Apollo, conducted docking analyses of an alternate docking system
  - Not a system used at that time, but some similarity to later systems
- This effort was very helpful in personal development of governing equations and coding (Fortran 4)
- Experience used in further development of analyses such as separation analyses
- Utilized Newton/Euler equations, vector analyses, structural dynamic response, etc.

ALTERNATE DOCKING CONCEPT



ALTERNATE DOCKING SYSTEM ANALYSIS

Solve loop eqn. for position of captured point

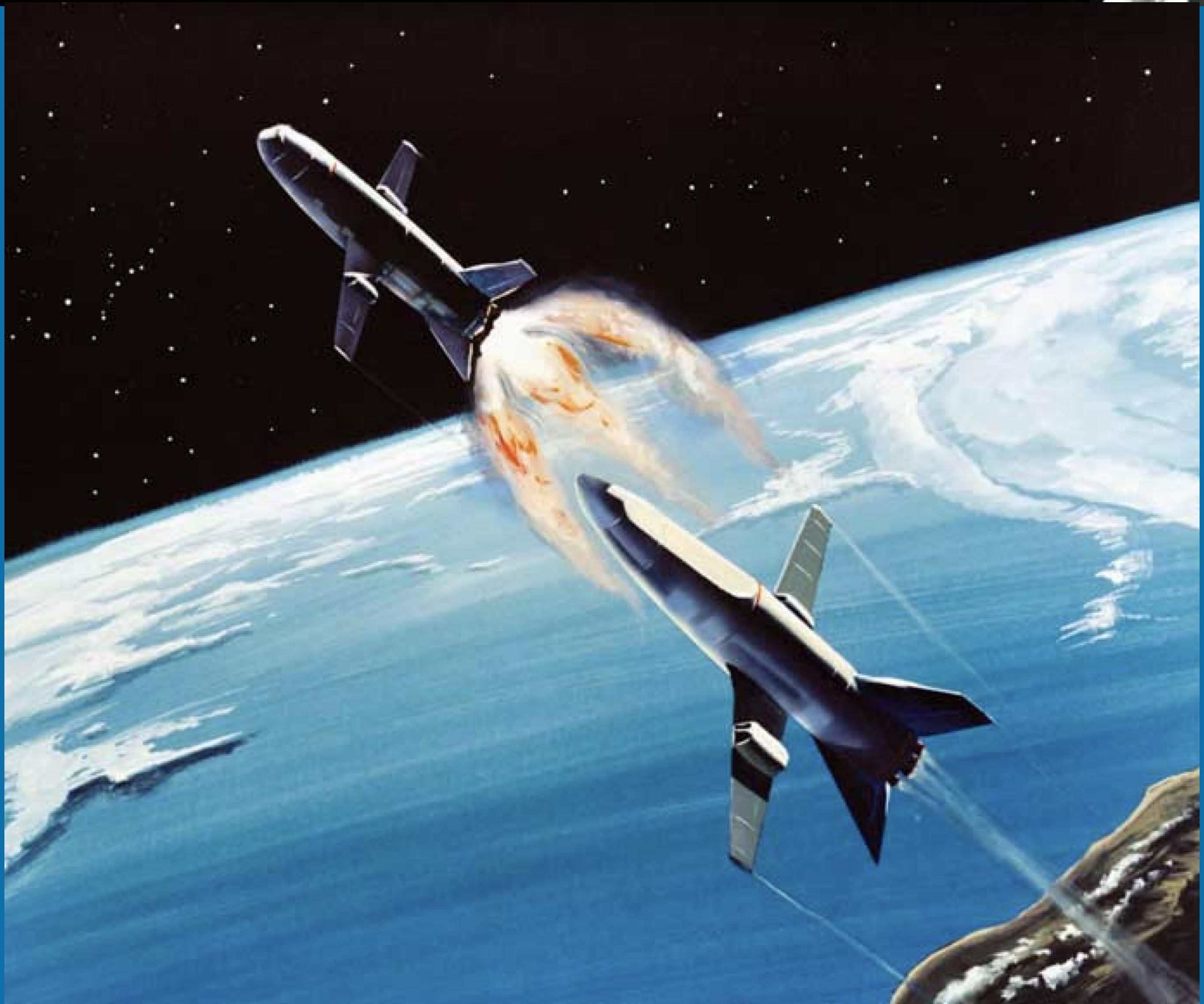


$$\vec{TC} = \vec{S1} + \vec{AF} - \vec{S2} - \vec{TCP} - \vec{RT}$$

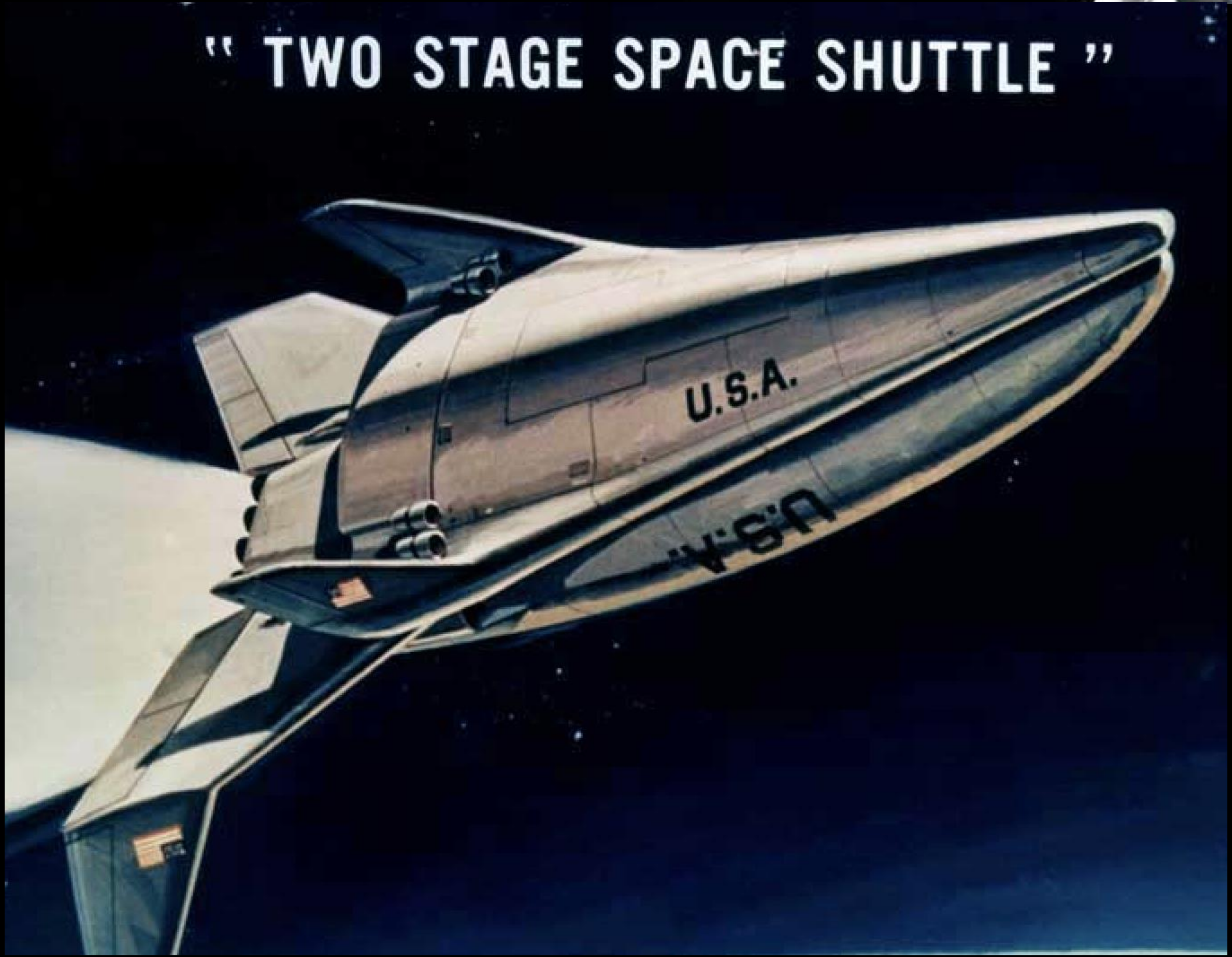
SEPARATION DYNAMICS

- Modeling of separation dynamics
  - Shuttle concepts
    - Flyback booster
    - Other
  - Baseline Shuttle parallel burn configuration
  - MS thesis on alternate separation concept

EARLY FLYBACK BOOSTER CONCEPT



LIFTING BODIES



ORBITER AND BOOSTER CONCEPT

SHUTTLE CONCEPT WITH OVER WING TANKS

SHUTTLE ASCENT CONFIGURATION BASELINE

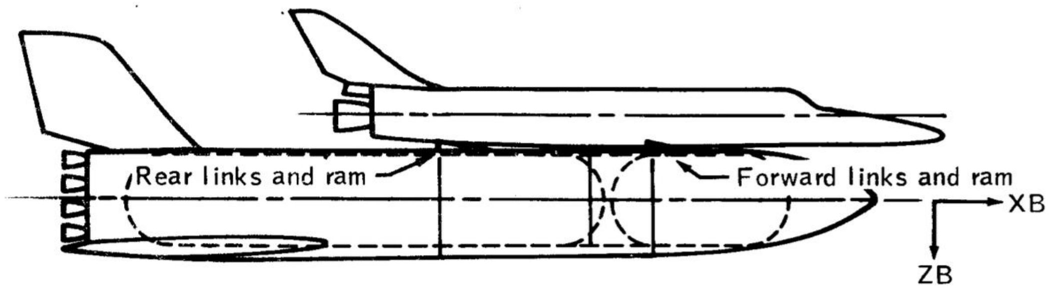
SEPARATION MODELING

- Newton/Euler equations were used to determine six degree-of-freedom vehicle motion of separating vehicles.
- Required input data included vehicle geometry, mass properties, aerodynamic properties, vehicle engine thrust, separation system thrusters and plume impingement forces.
- Vector analyses were used to track relative motion and to calculate forces in any mechanisms or attach linkage hardware.
- Basic aerodynamic lift, drag, side force and moment equations were applied, utilizing test measured aerodynamic coefficients.
- Simulations were made to determine affects of plume impingement and aerodynamics on relative motion during separation of the orbiter from external tank, orbiter/tank from boosters, and orbiter from tank/boosters.
- Conditions addressed both nominal and abort conditions for the various configurations

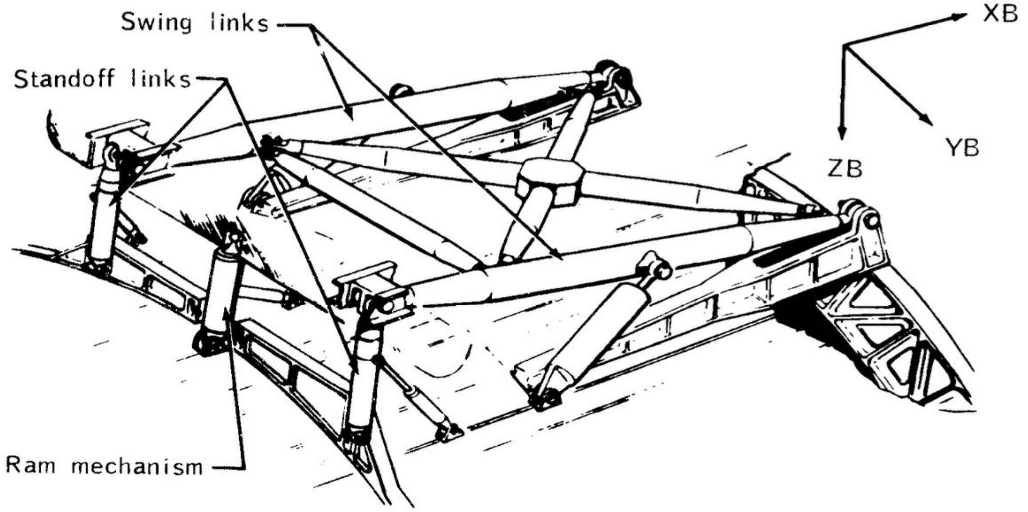
MS THESIS ON SEPARATION

- In 1972, and as part of a Masters program at the University of Houston, a mathematical model to simulate staging/separation dynamics of an alternate separation concept was developed.
- The studied concept could be used to separate the orbiter from the external tank, but differed from the baseline in that a piston/ram assisted swing-link system was assessed.
  - The baseline Shuttle separation of the tank from the orbiter separates at the forward and aft attach points and uses thrusters to facilitate separation
  - The alternate link system would utilize an active separating force and linkages to create a positive separation motion.
- This concept was assessed to enhance separation capability at off-nominal conditions where aerodynamic forces might oppose separation motion.
  - The model included kinematics and dynamics of the staging mechanism, interface link modeling, thrust forces thrust vector control, rigid body dynamics, etc.
  - Thesis also include structural dynamics. equations, but not vehicle modes were available at that time

UH MS THESIS ON SEPARATION CONCEPT



(a) Launch configuration and section locations.



(b) Forward or rear link-ram section.

PRZEMIENIECKI (AFIT) BEAM EQUATIONS

$$
\begin{Bmatrix} F1 \\ F2 \\ T4 \\ T6 \\ F7 \\ F8 \\ T10 \\ T12 \end{Bmatrix}
=
\begin{bmatrix}
AE/\ell & & & & & & & \\
0 & 12EI/\ell^3 & & & & & \text{Symmetric} & \\
0 & 0 & JG/\ell & & & & & \\
0 & 6EI/\ell^2 & 0 & 4EI/\ell & & & & \\
-AE/\ell & 0 & 0 & 0 & AE/\ell & & & \\
0 & -12EI/\ell^3 & 0 & -6EI/\ell^2 & 0 & 12EI/\ell^3 & & \\
0 & 0 & -JG/\ell & 0 & 0 & 0 & JG/\ell & \\
0 & 6EI/\ell^2 & 0 & 2EI/\ell & 0 & -6EI/\ell^2 & 0 & 4EI/\ell
\end{bmatrix}
\begin{Bmatrix} U1 \\ U2 \\ U4 \\ U6 \\ U7 \\ U8 \\ U10 \\ U12 \end{Bmatrix}
$$

APPROACH AND LANDING TESTS (ALT)

- Captive flights with Orbiter Enterprise mounted to 747
  - Enterprise was only suborbital vehicle
  - A tail code was used to reduce adverse aerodynamic effects
- Five separation flights (June – Oct 1977)
- Separation analyses conducted
  - Newton/Euler modeling
  - Predicted motion/clearances

JOHN KIKER AND ALT MODEL

APPROACH AND LANDING TEST (ALT) 1977

STAR TREK VISIT TO ENTERPRISE AT EAFB

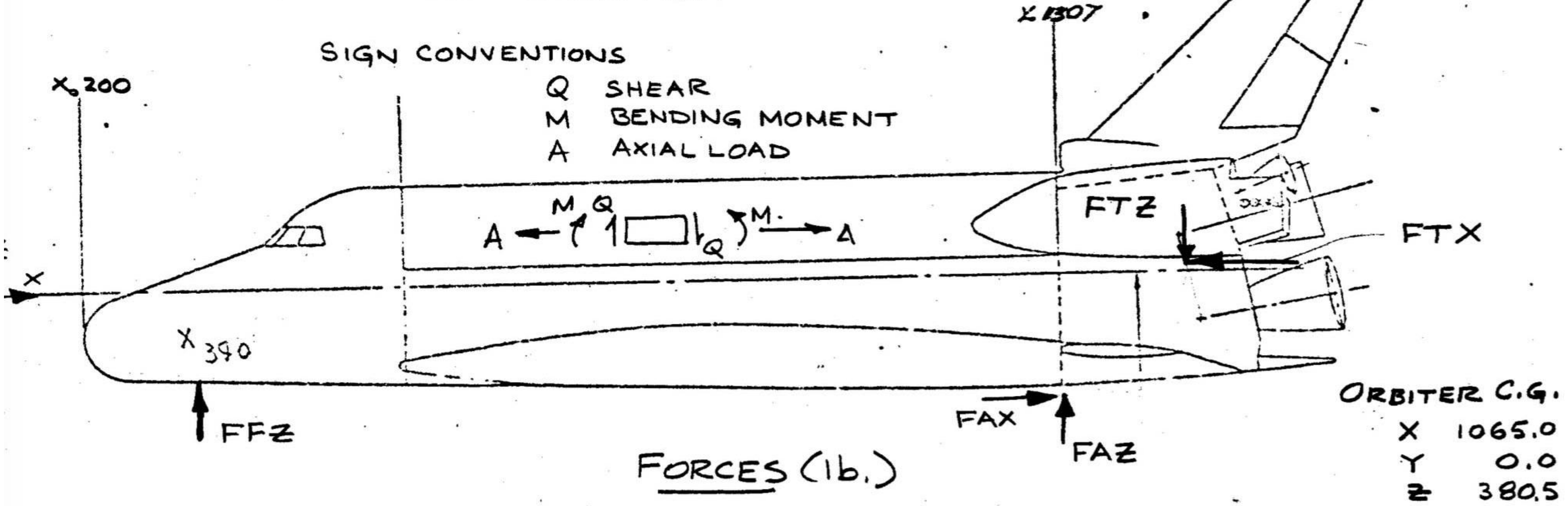
ALT SEPARATION AUG 1997

SHUTTLE ORBITER LOADS

- A structural loads computer code was developed to predict Orbiter shear, bending moment and axial loads were calculated for various flight load conditions, such as liftoff, pre-staging/post-staging conditions, entry and landing
- These conditions represented significant structural loading events and represented an event of significant load change. The methodology for the loads calculations is provided in these linked notes.
- Ascent design type cases were analyzed by calculating forces at the limits of angle-of-attack , engine gimbal angles extremes and maximum thrust levels. Orbiter shear, bending moment and axial loads were calculated for these design cases.
- Wing loads were calculated for return to launch site abort cases. Design type cases with high aerodynamic pressure, maximum or minimum angle-of-attack and high mach number were assessed. These analyses were focused on wing loading and provided wing root bending, torsion and shear.
- All of these analyses were compared to initial design loads used by the Shuttle prime contractor for orbiter structural sizing, to assure adequate coverage of all design conditions existed.

ORBITER LOADS AT SRB STAGING

FIGURE 1. EXTERNAL FORCES APPLIED TO ORBITER



FORCES (lb.)

CASE	FFZ	FAX	FAZ	FTX	FTZ
PRE-STAGING UNDERTRIM	70,800	1,329,400	230,800	1,494,800	306,850
PRE-STAGING OVERTRIM	60,100	1,327,000	272,000	1,483,200	358,830

SHUTTLE ORBITER LANDING LOADS

- The orbiter vehicle utilizes an aircraft type tricycle landing gear system.
- The nose gear and both main gear have two tires with a forward-facing drag brace assembly.
- A very detailed mathematical model and computer simulation of the landing system (G.Zupp)
- The simulation included modeling of the gear load/stroke characteristics, tire/wheel and structural member stiffness, temperature affects, tire/ground friction, damping and orbiter vehicle aerodynamics.
- As in other simulations, vector analysis along with Newton/Euler equations was used to calculate forces and motion.
- The simulation was used to predict tire loads and loads at the gear trunnion/orbiter attach points. Tire loads were utilized in initial tire development. Trunnion loads were used to assess orbiter vehicle loading.
- Analyses included gear drop test data, and from Approach and Landing Test (ALT) flight data

ORBITER LANDING GEAR

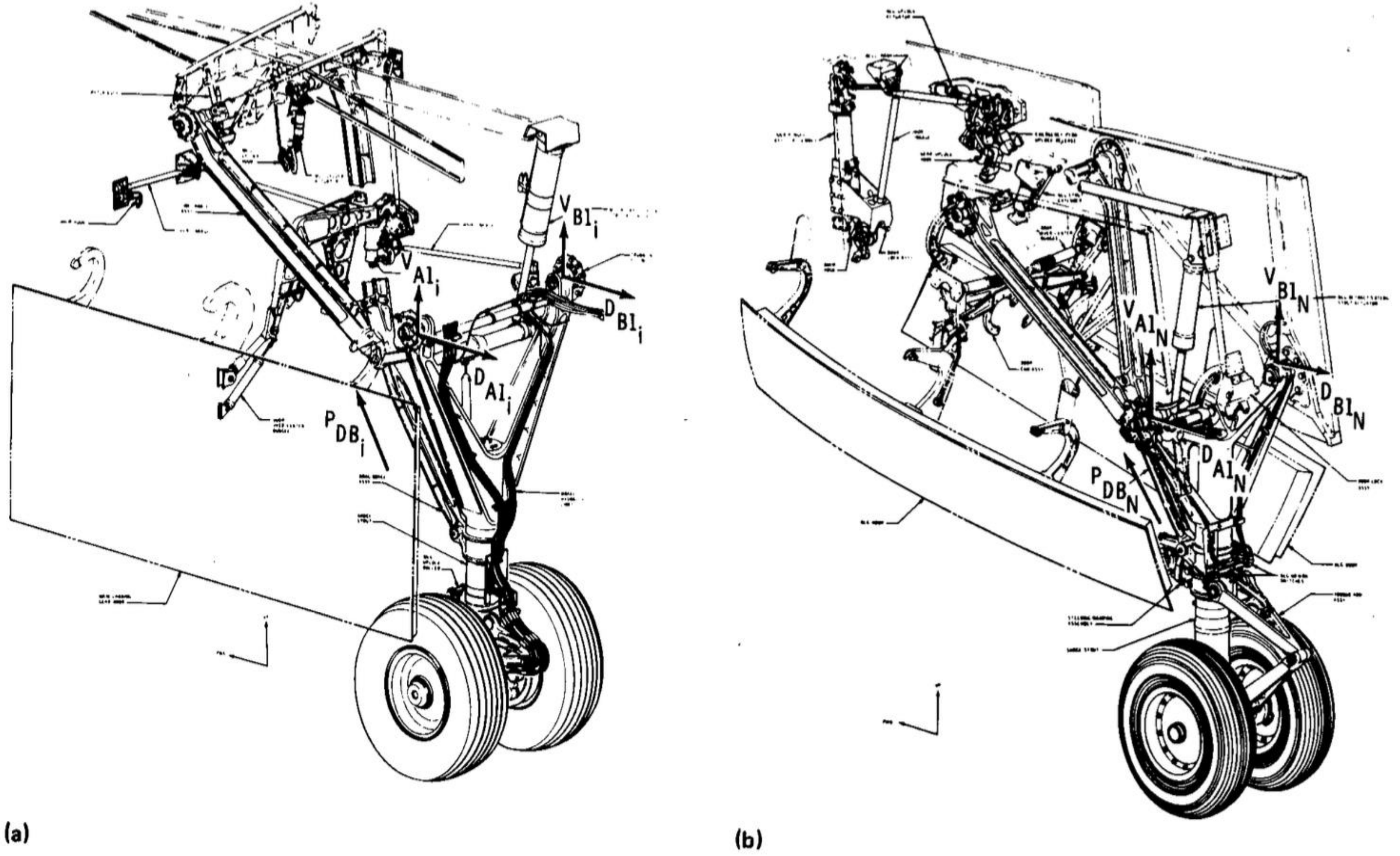


FIGURE 2.—Landing gear chassis assembly. (a) Main landing gear. (b) Nose landing gear.

LANDING GEAR IDEALIZATION

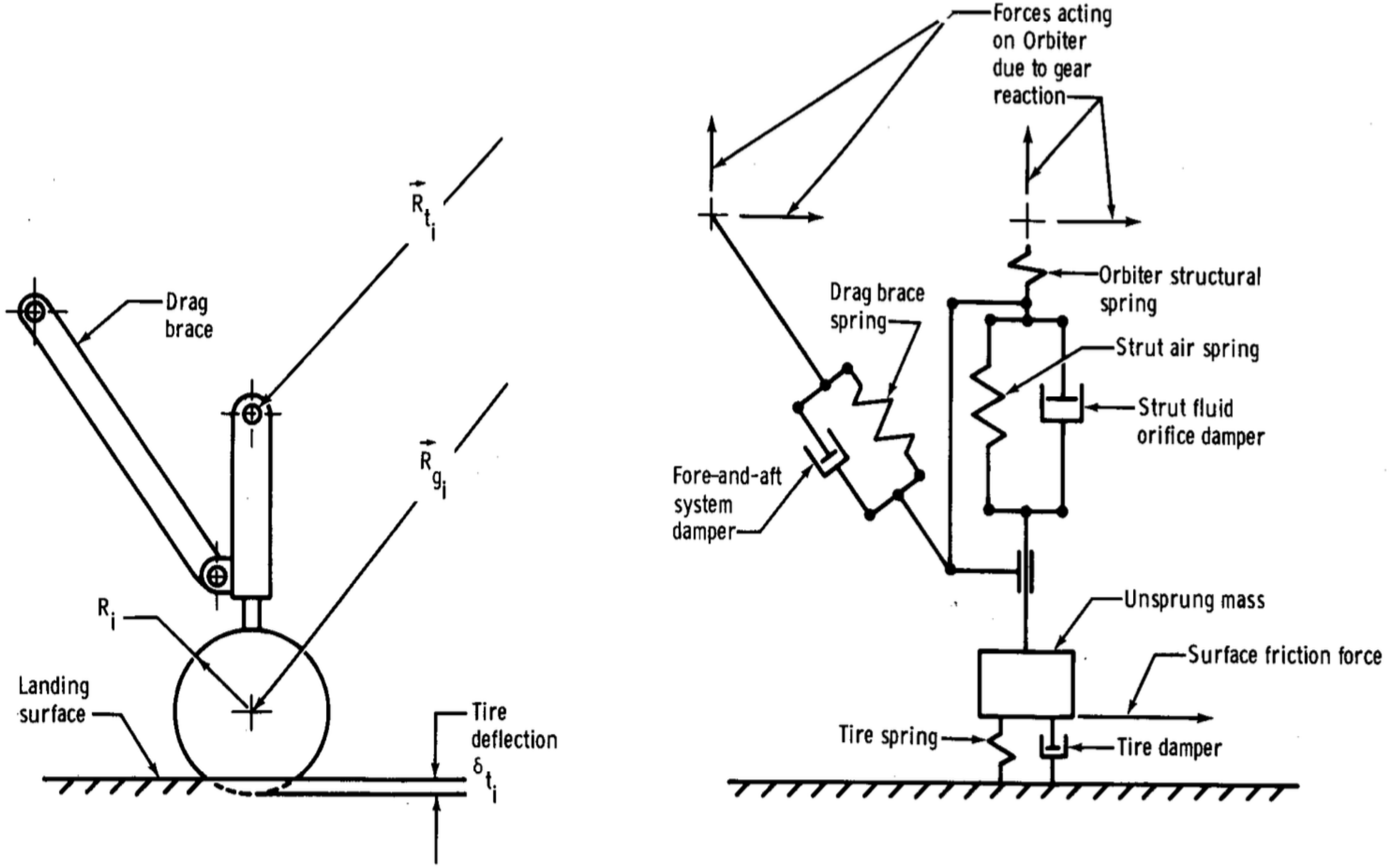
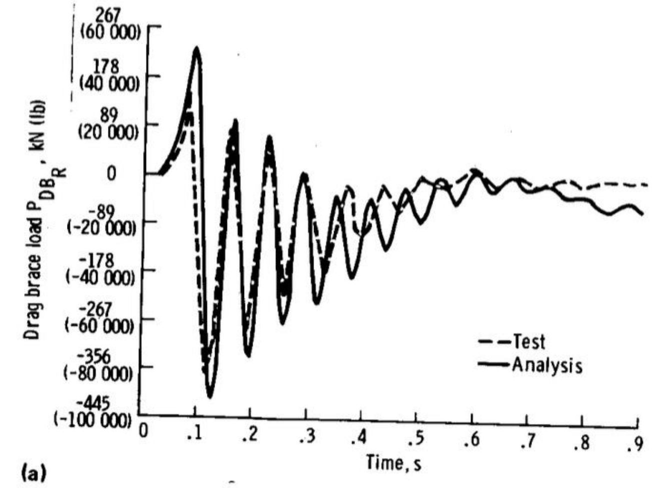
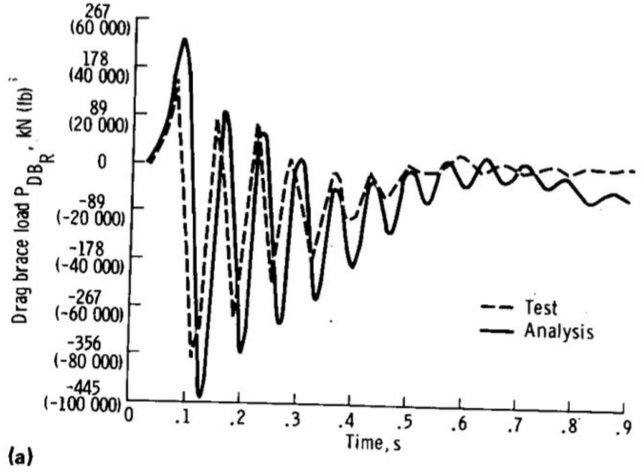
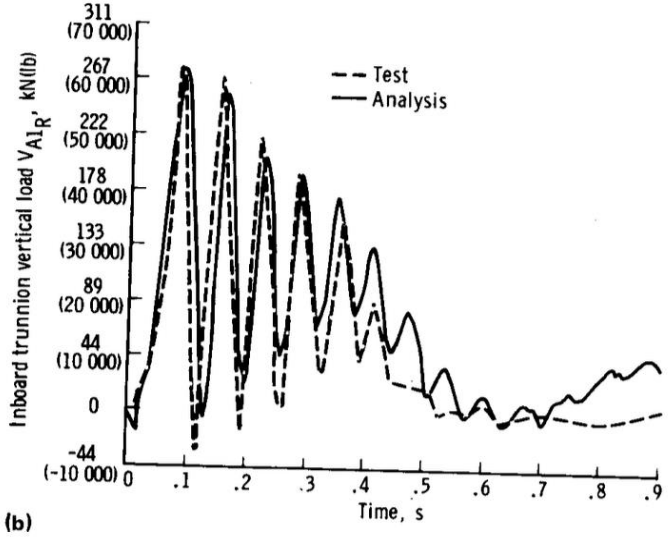


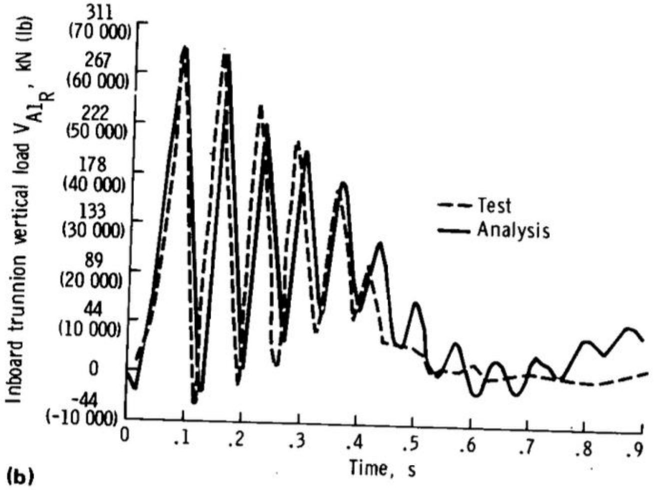
FIGURE 3.—Landing gear idealization.

LANDING GEAR DATA CORRELATION FOR ALT FF5









ORBITER TIRE LOADS

- From early in the Shuttle Program, tire loads were known to be high due to a negative angle of attach during rollout.
- The negative angle resulted from the as-designed nose gear length, as compared to main gear length and to fuselage attach point.
- Initial estimates of maximum tire loads calculated using orbiter mass properties, gear location geometry, and preliminary aerodynamic forces.
- Tire load increments were estimated for variables including crosswind, aerodynamic tolerance, runway crown, manual versus automatic control, turbulence, and runway roughness.
- Loads were calculated for landings at Edwards AFB, KSC, and the Northrup site at White Sands NM
- Tire wear was also assessed for the KSC runway

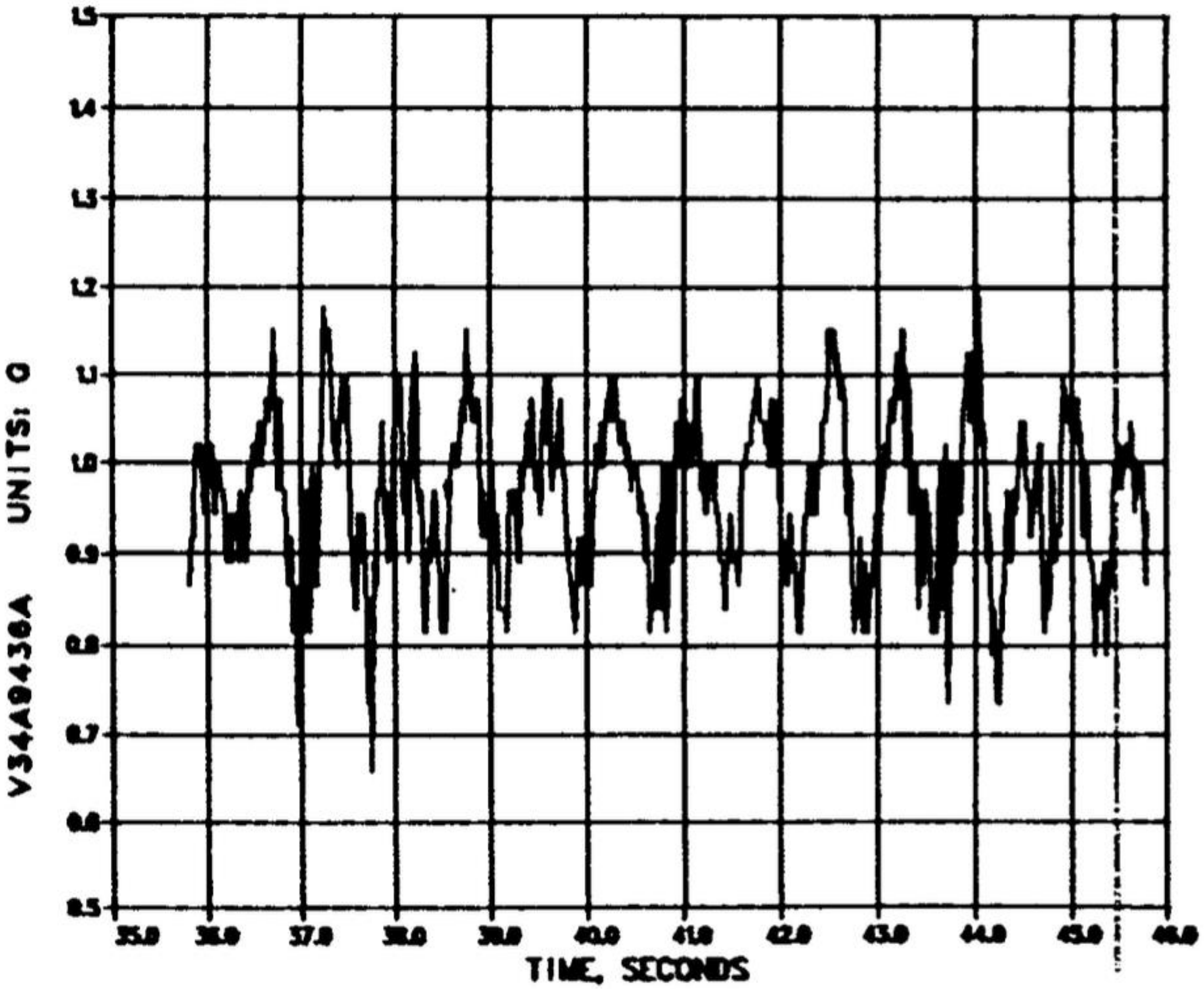
STS5 LANDING AT EAFB

RESPONSE FROM ROLLOUT TIRE LOADS, EAFB

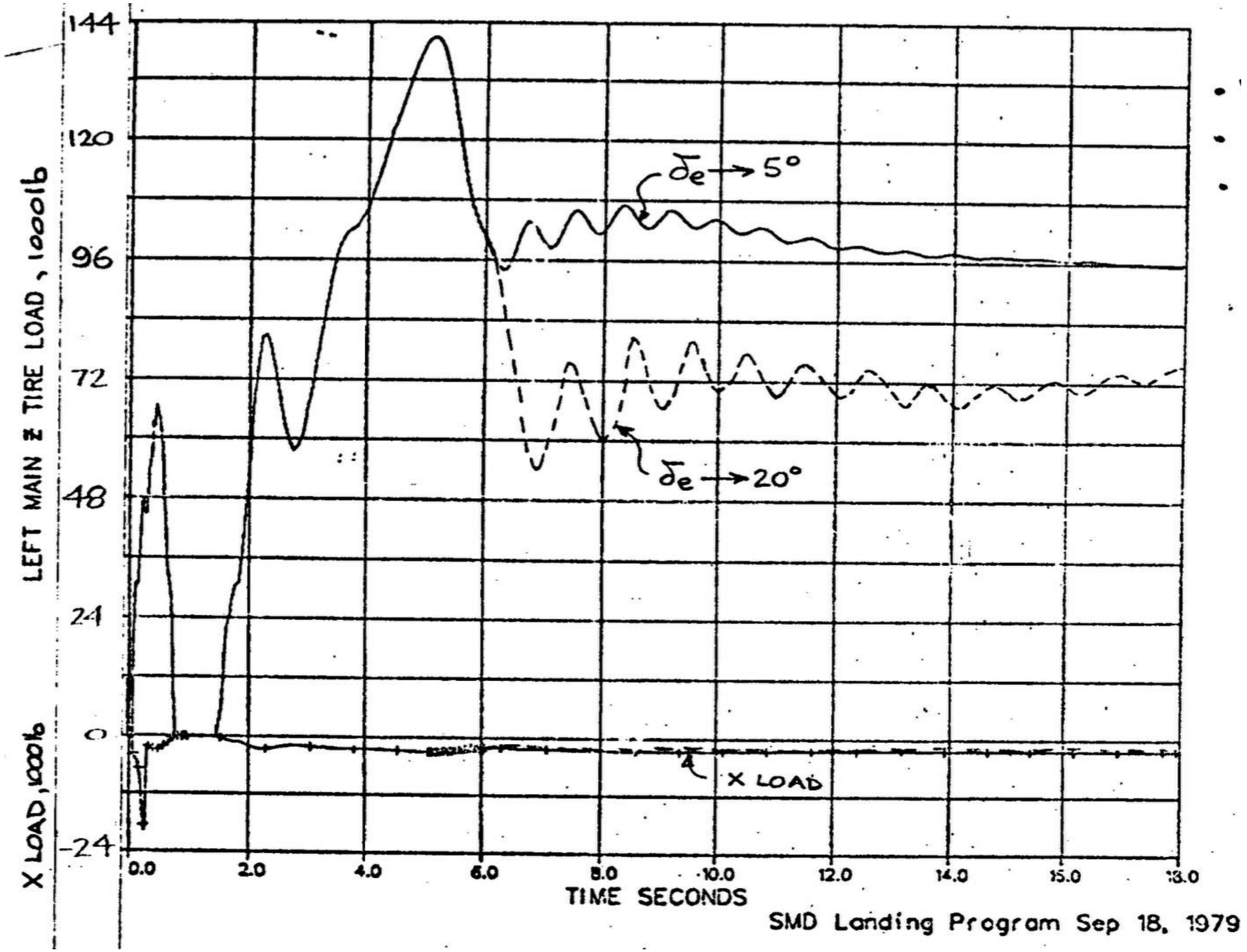
$\ddot{Z}_{1294}$

STS5

EDWARDS RUNWAY



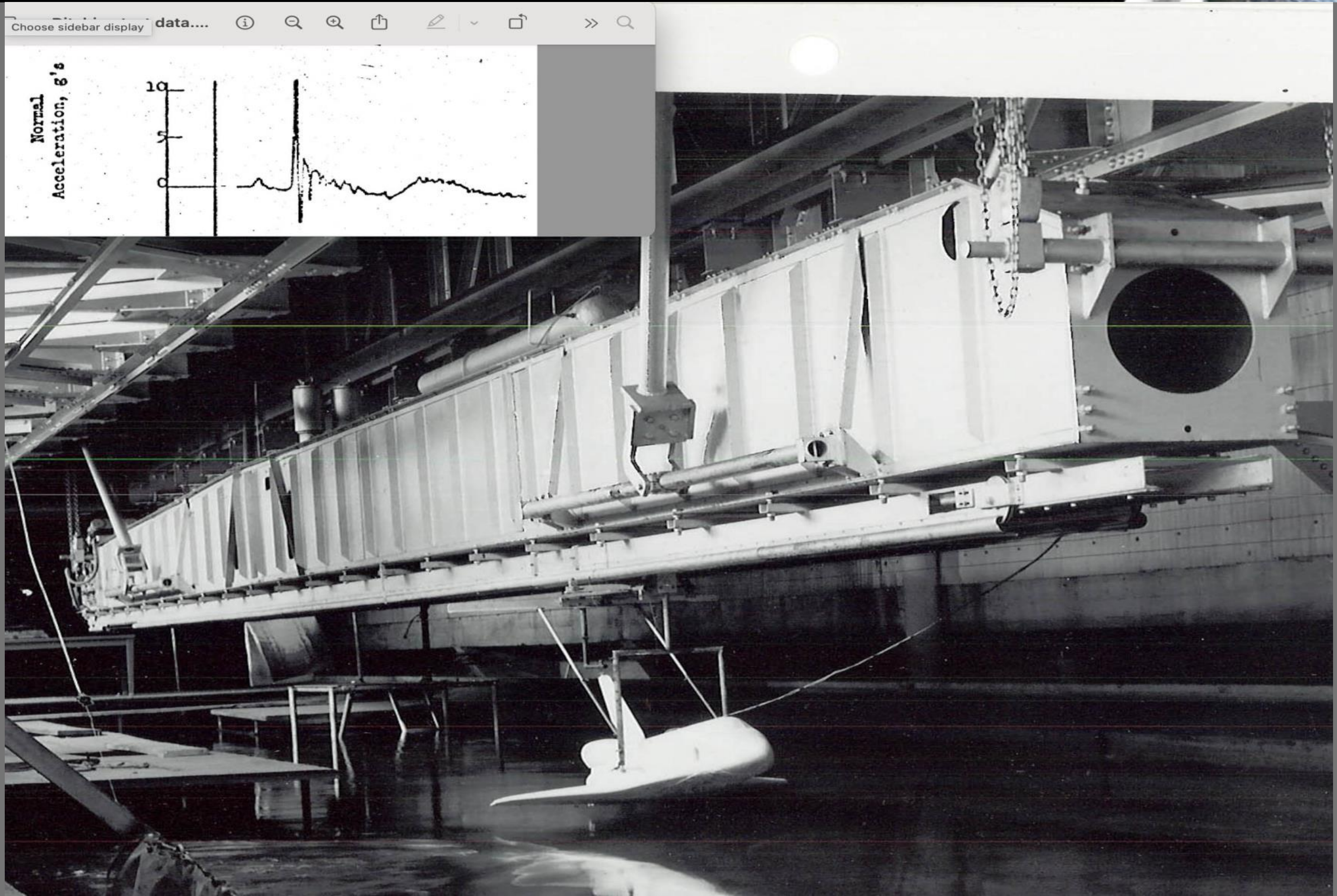
MAIN GEAR TIRE LOAD VS. ELEVON POSITION



ORBITER DITCHING

- Test and analyses were done to assess loading for possible water impact of the Shuttle Orbiter
- Scale model tests were done at LARC
- Acceleration data was measured in the tests
- No wetted area was measured, so predicting pressures on the Orbiter was problematic
- Mil Spec has equations for pressure distribution during ditching, but were much different than data from tests

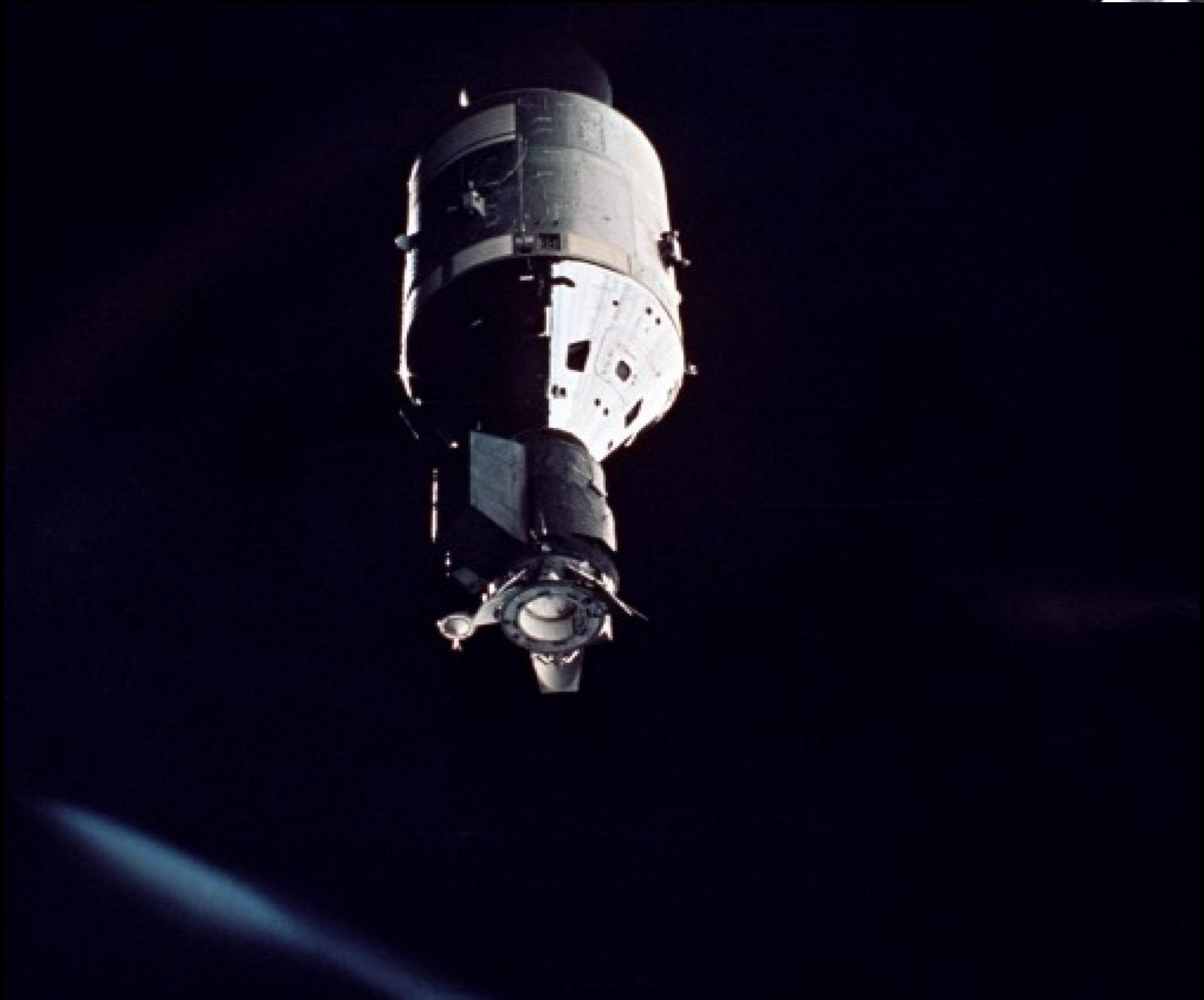
ORBITER MODEL DITCHING TEST



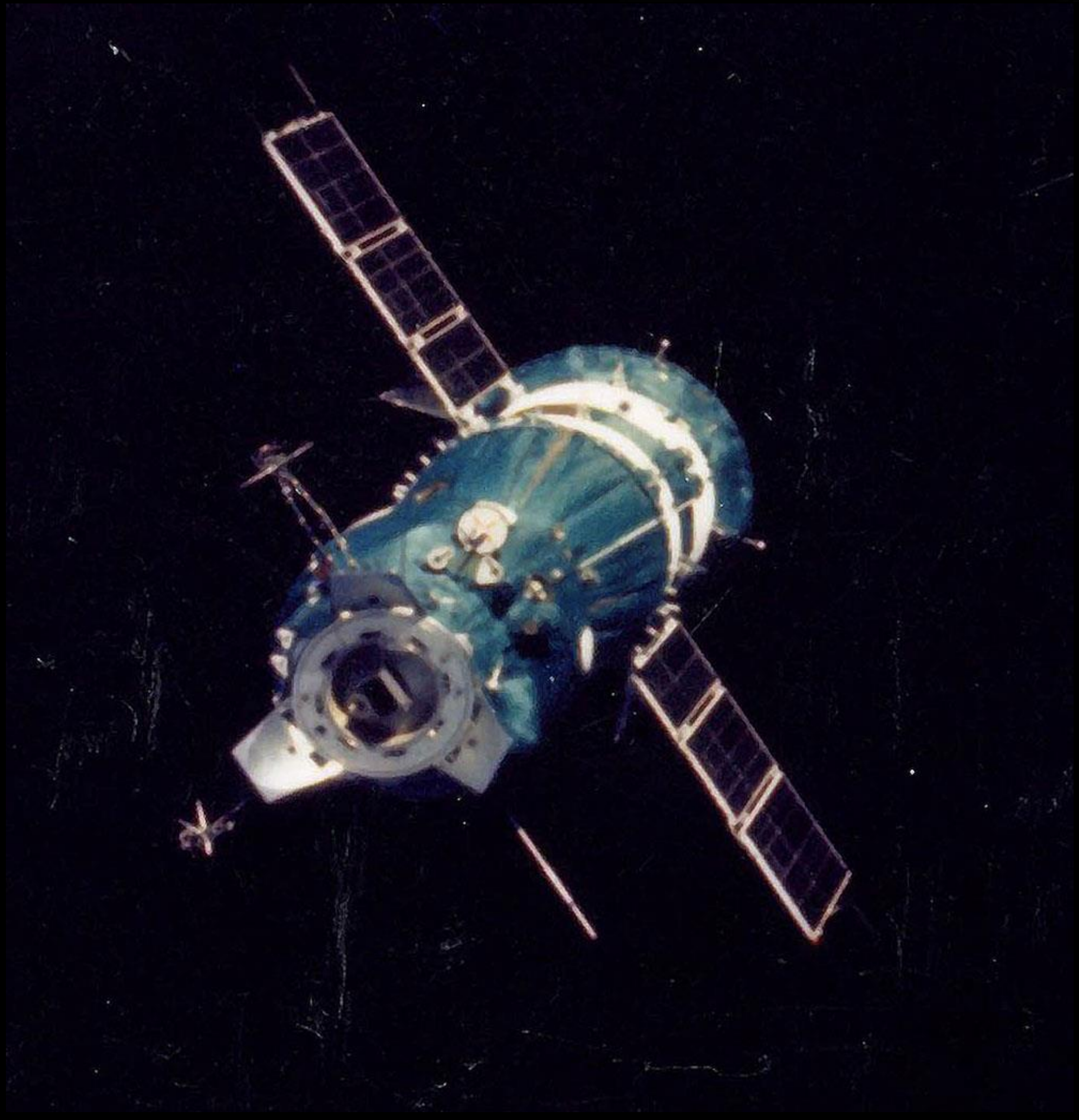
APOLLO SOYUZ TEST PROJECT (ASTP)

- Docking capture performance and loads were calculated for both the Apollo vehicle and Soyuz vehicle and docking module for a variety of loading events.
- Results were used to assess loads against existing design capability of these vehicles and to determine any required operational constraints.
- Analyses were conducted for a number of loading events:
  - vehicle docking,
  - reaction control system(RCS) operation for the mated configuration,
  - CM service propulsion system(SPS) thrusting, and
  - crew exercising.
  - Soyuz solar panel loads

ASTP CSM PLUS DOCKING ADAPTER



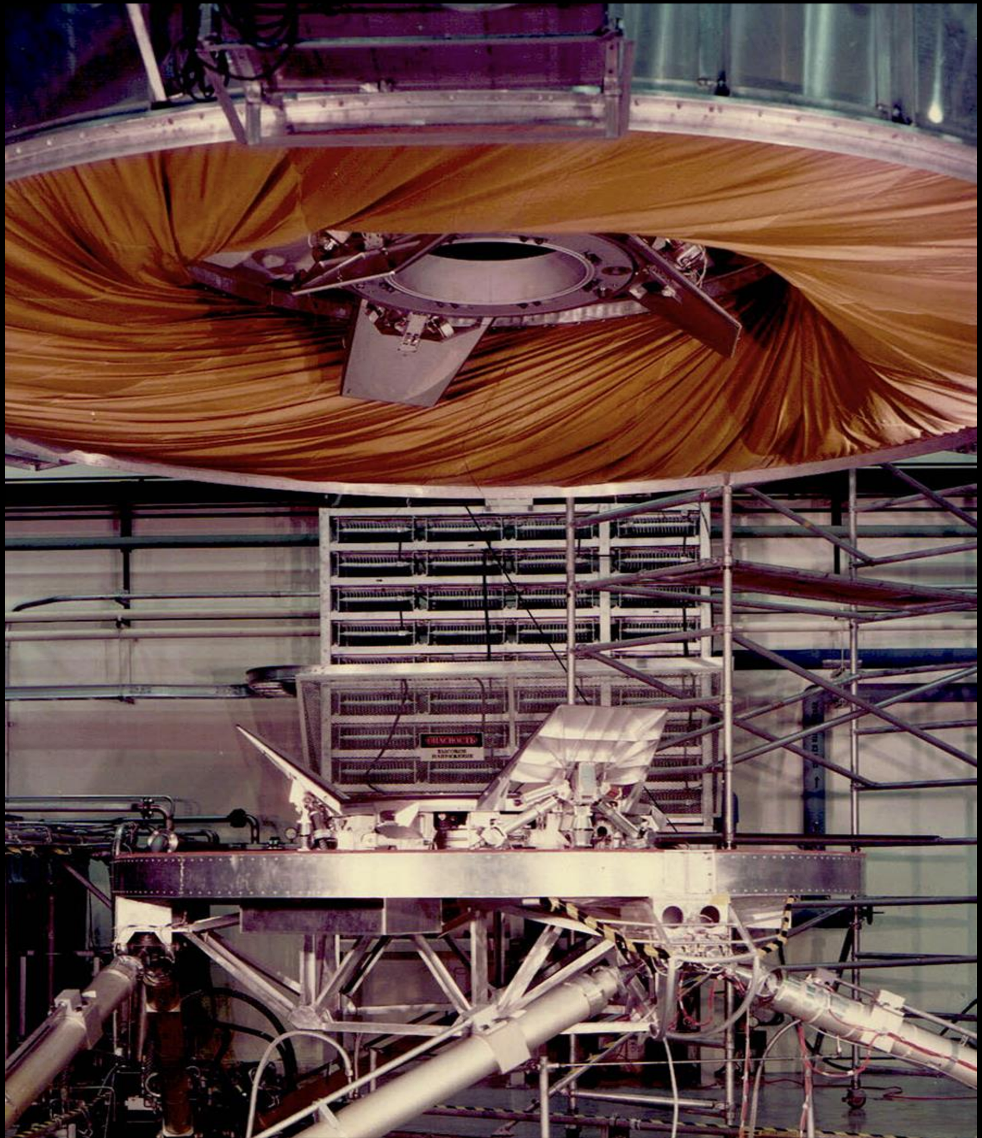
SOYUZ ON ASTP FLIGHT



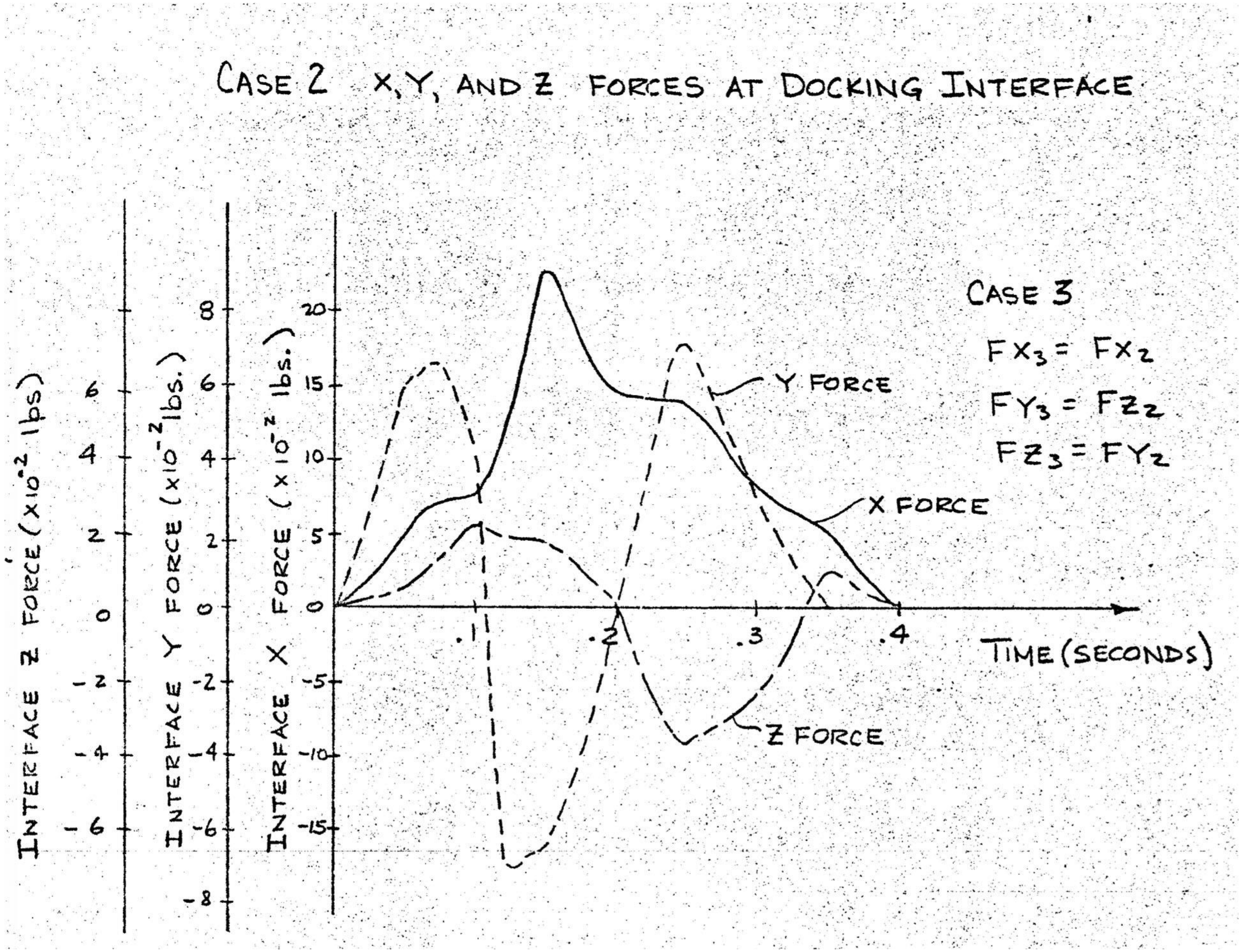
ASTP ILLUSTRATION

ASTP MOCKUP

ASTP TEST FACILITY AT JSC



ASTP DOCKING FORCES



SHUTTLE PAYLOAD BAY DATA

- Dynamic loads from conditions such as liftoff and landing produce significant design load conditions for payloads launched by the Space Shuttle.

- Payload flight configuration unique dynamic analyses of these loading conditions were conducted since inception of the Shuttle Program.
  - The first payload verification loads cycle was done for the DFI pallet which was in the payload bay for STS-1

- One of the earliest loads assessments for Shuttle payloads, was a load alleviation study conducted for payloads that had been previously design for launch on expendable launch vehicles (ELV). The ELV load requirements for lateral loads, were in some cases lower than Shuttle abort loads.

SHUTTLE VEHICLE

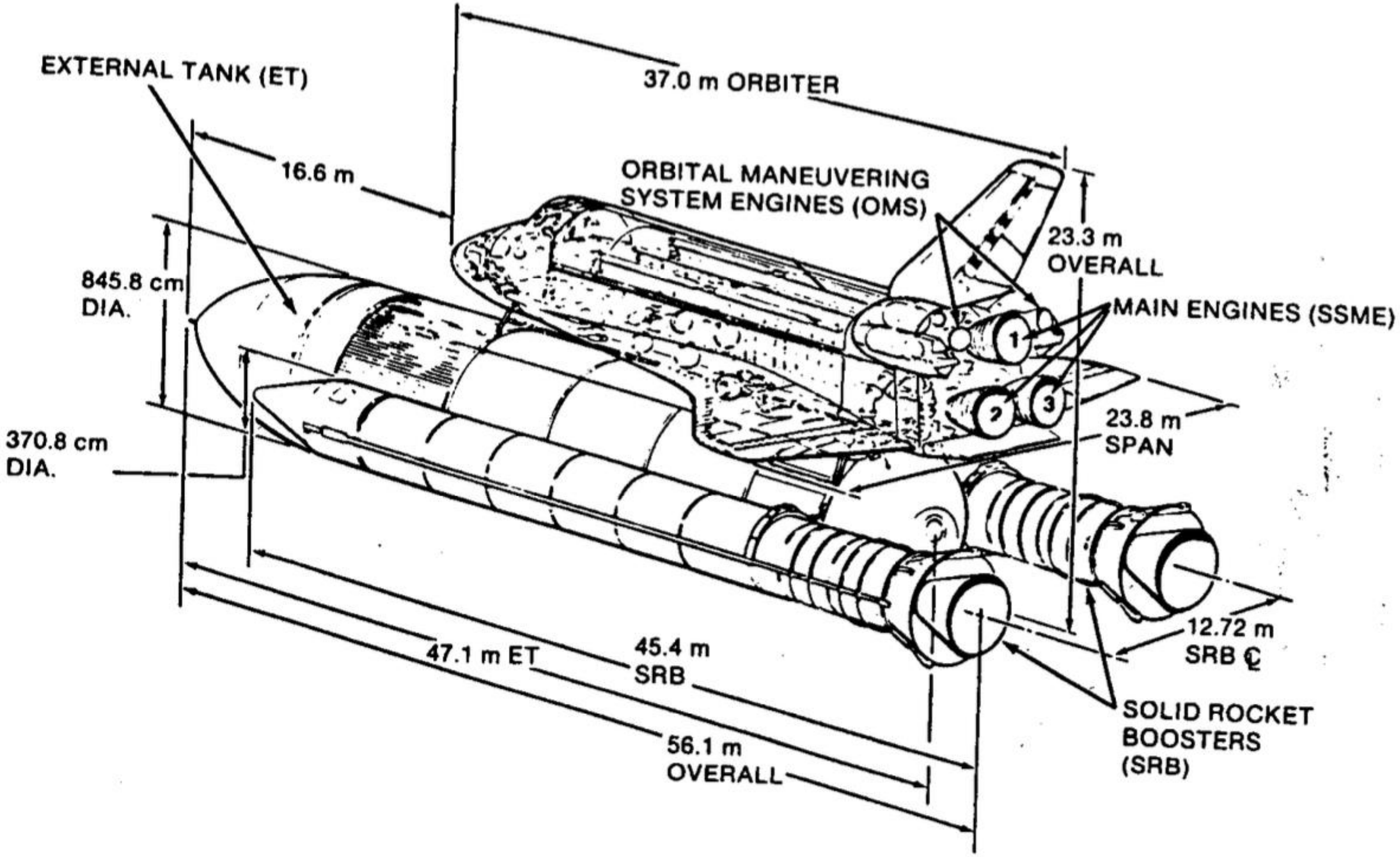


Figure 1. The Space Shuttle vehicle.

SPACE SHUTTLE DYNAMIC LOAD EVENTS

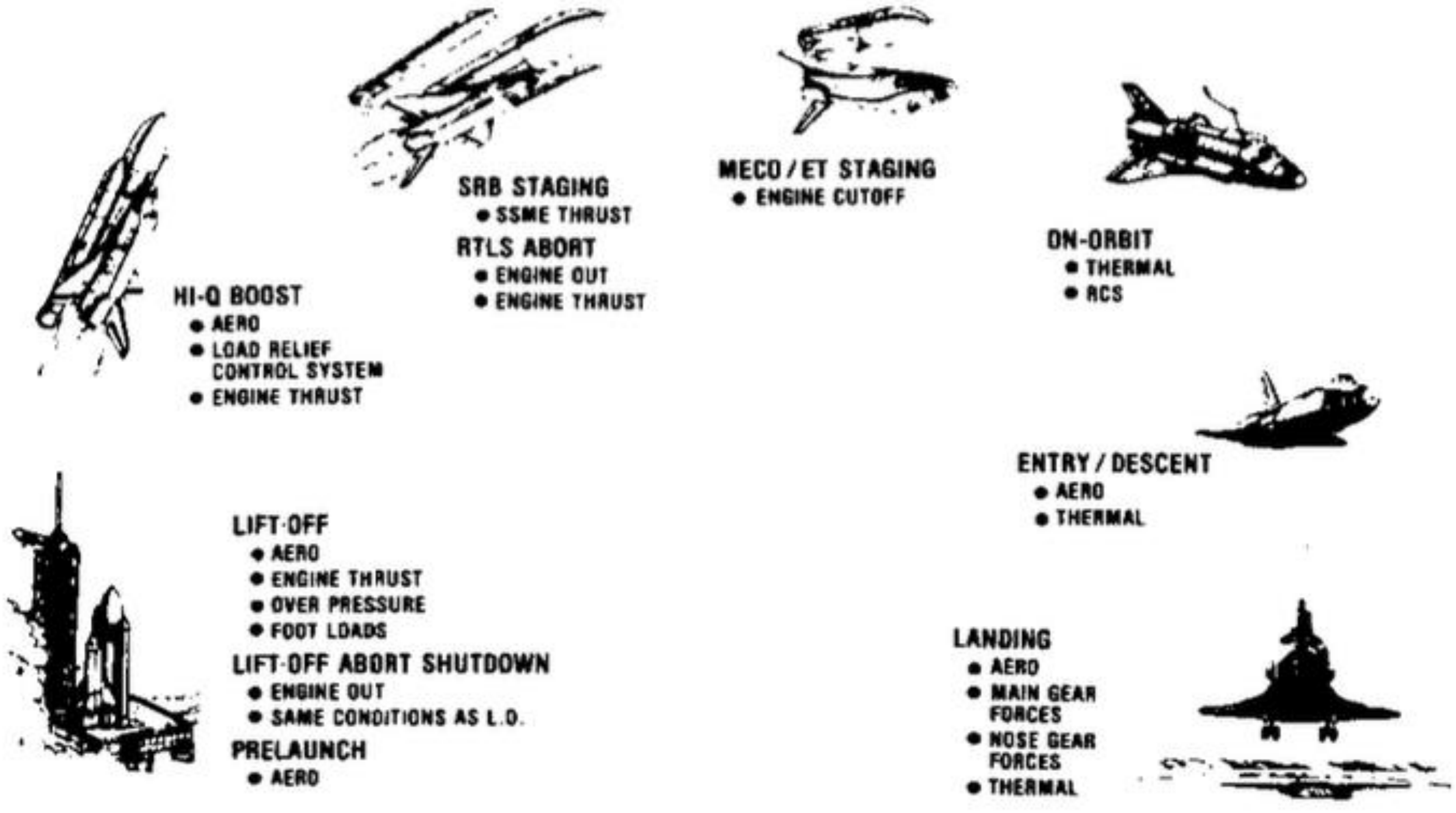
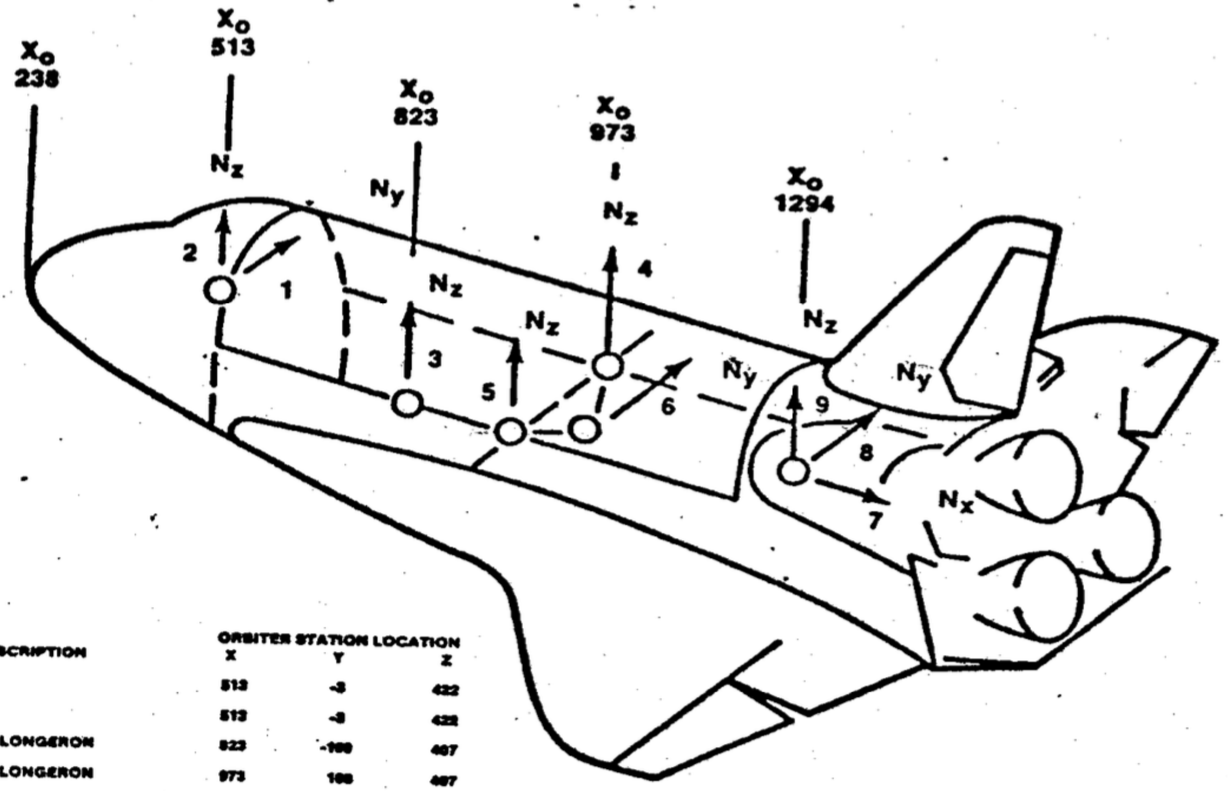


Fig. 2 Shuttle dynamic loads flight events.

DFI PALLET ON STS-1

ORBITER PAYLOAD BAY ACCELEROMETERS



	MEASUREMENT NO.	DIR.	RANGE (g)	LOCATION DESCRIPTION	ORBITER STATION LOCATION X	Y	Z
1.	V33A9215A	Y	-2, +2	CREW CABIN	513	-3	422
2.	V33A9216A	Z	-2, +6	CREW CABIN	513	-3	422
3.	V34A9430A	Z	-2, +6	CARGO BAY, SILL LONGERON	823	-100	407
4.	V34A9431A	Z	-2, +6	CARGO BAY, SILL LONGERON	973	100	407
5.	V34A9432A	Z	-2, +6	CARGO BAY, SILL LONGERON	973	-100	407
6.	V34A9433A	Y	-2, +2	CARGO BAY NEAR KEEL LONGERON	979	+0	305
7.	V34A9434A	X	+2.4, -2.5	CARGO BAY, AFT BULKHEAD	1294	+3	296
8.	V34A9435A	Y	-2, +2	CARGO BAY, AFT BULKHEAD	1294	+3	300
9.	V34A9436A	Z	-1.5, +6	CARGO BAY, AFT BULKHEAD	1294	+6	300

Fig. 3 Orbiter low-frequency accelerometers.

STS3 SRB THRUST DATA

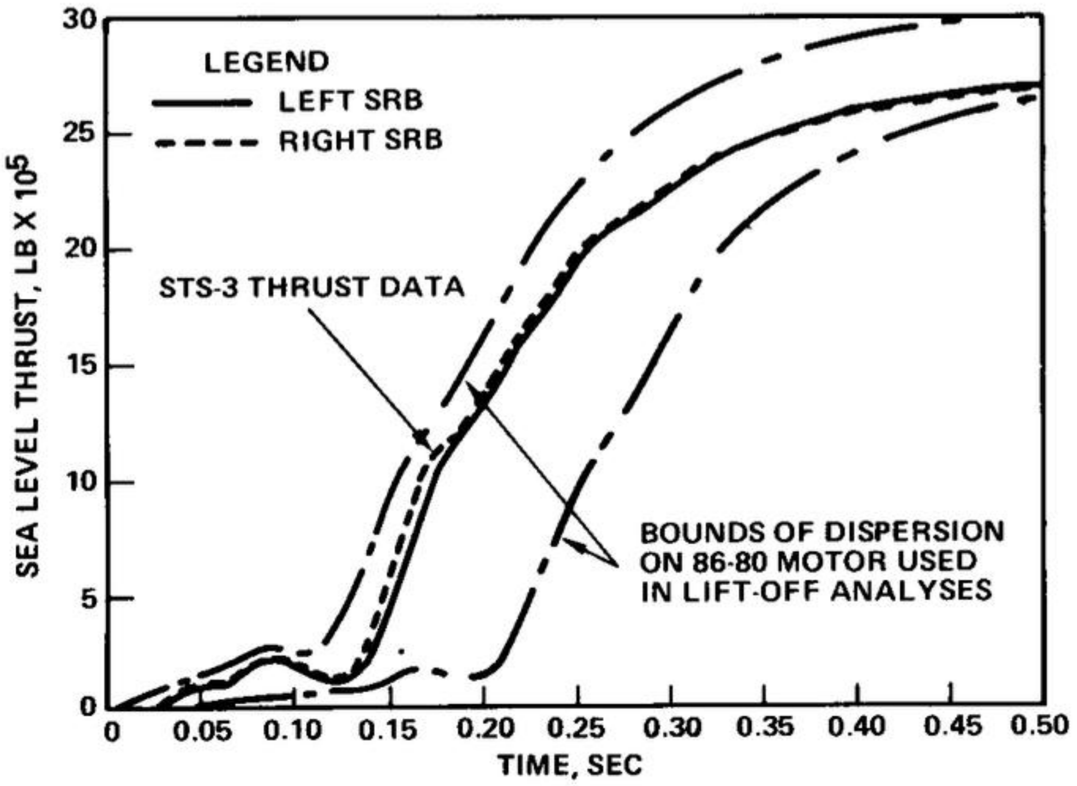


Fig. 10 Comparion of STS-3 thrust buildup to dispersions on 86-80 motor.

STS3 LIFTOFF DATA AND ANALYSIS

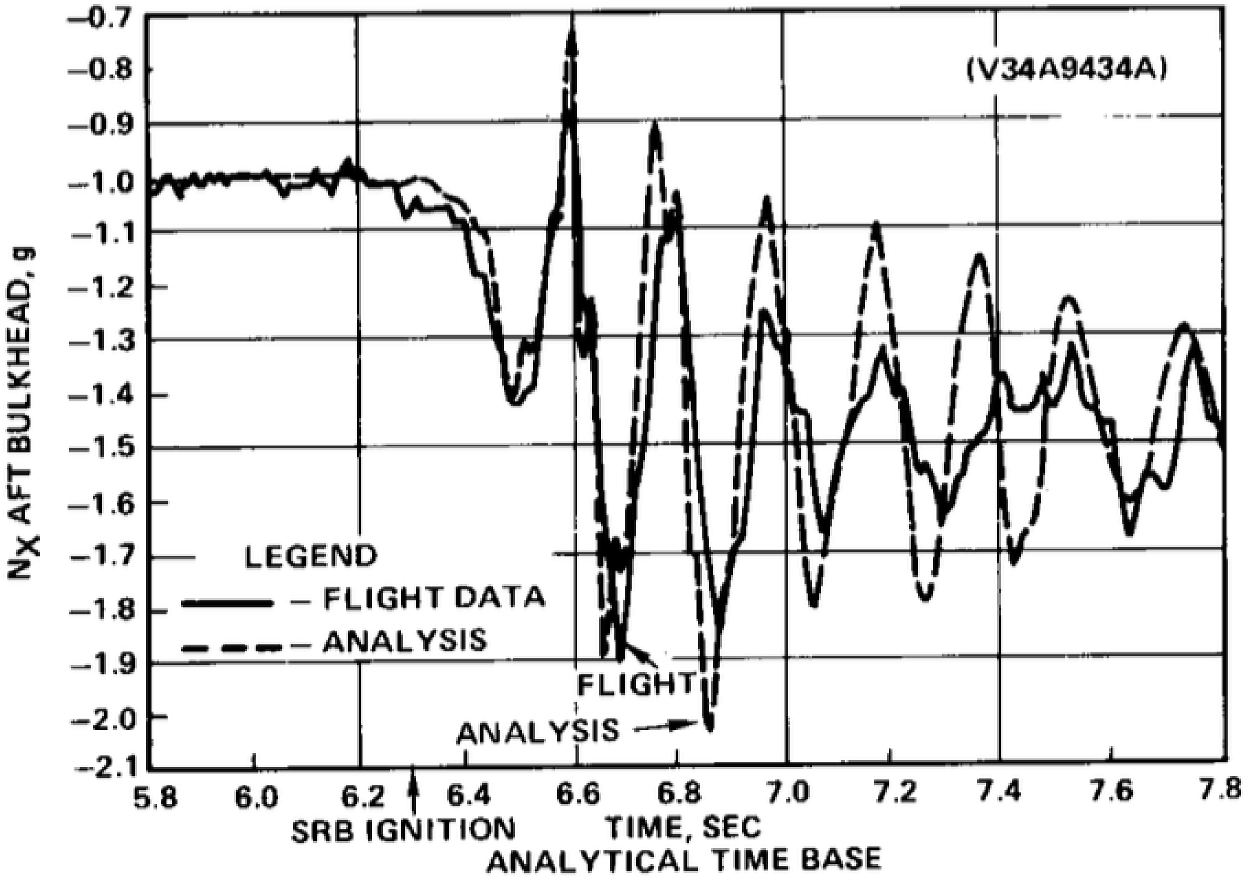
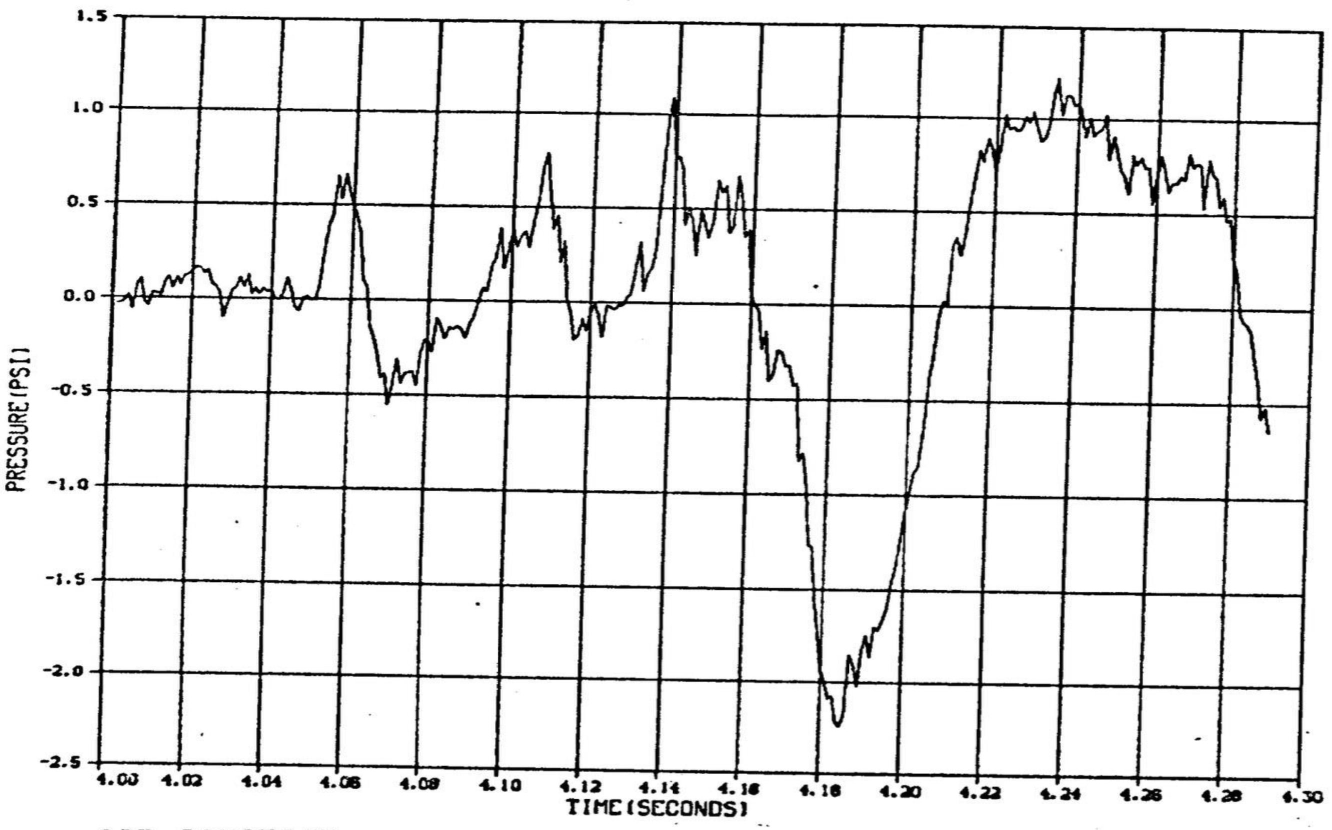


Fig. 17 Correlation with aft bulkhead N_X for STS-3 lift-off— no overpressure.

STS1 OVERPRESSURE



SRB IGNITION
@ 3.91

FIG. 5 DIFFERENTIAL PRESSURE ACROSS ORBITER AFT FUSELAGE FOR STS-1 LIFTOFF

- STS1 experienced a high overpressure at SRB ignition
- Starting with STS2, a water suppression system was added to the KSC launch pad
  - It significantly reduced the overpressure

SOCK SPECTRA OF PAYLOAD BAY DATA

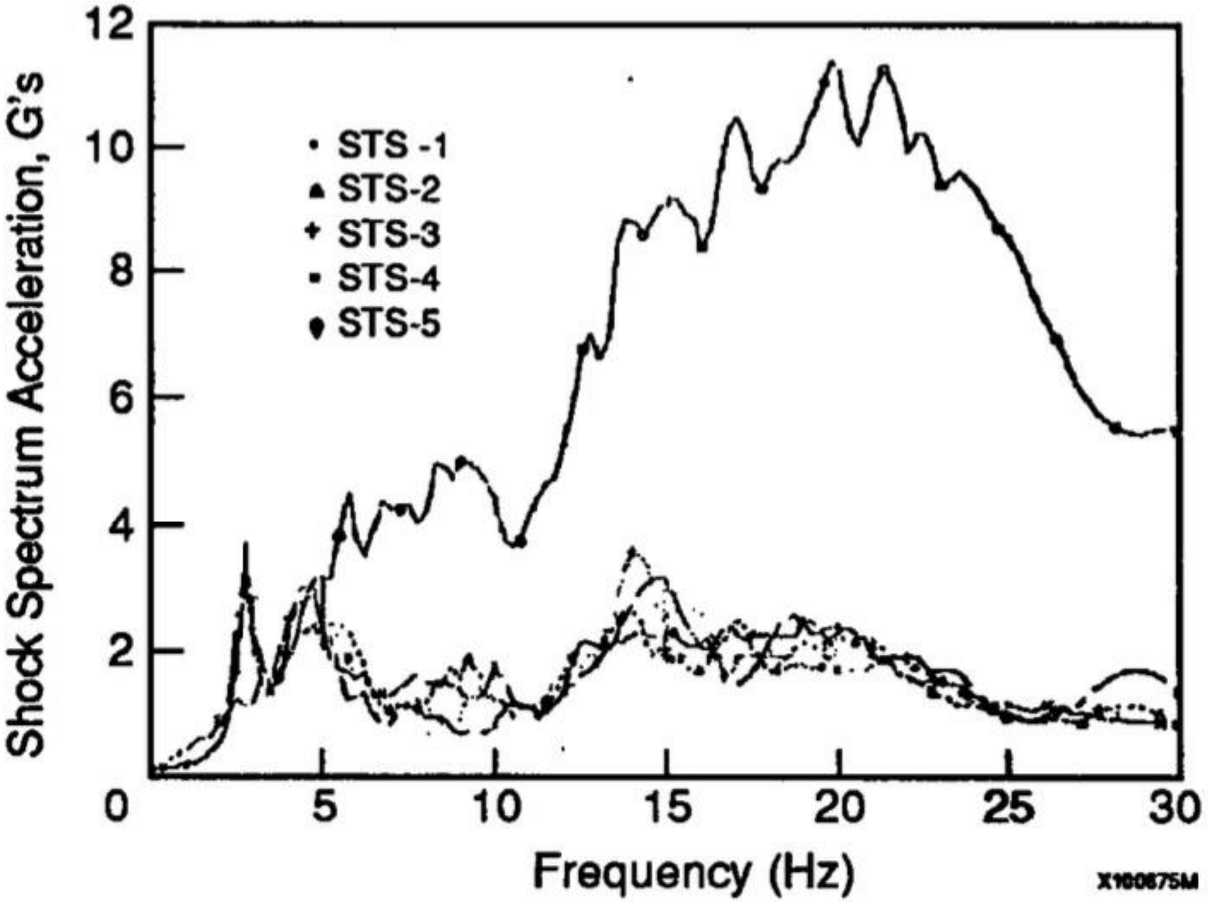


Figure 2: Lift-off shock spectra for Z acceleration at X = 973 for STS-1 through STS-5.

CONCLUSION

- Only a brief summary of many technical projects supported

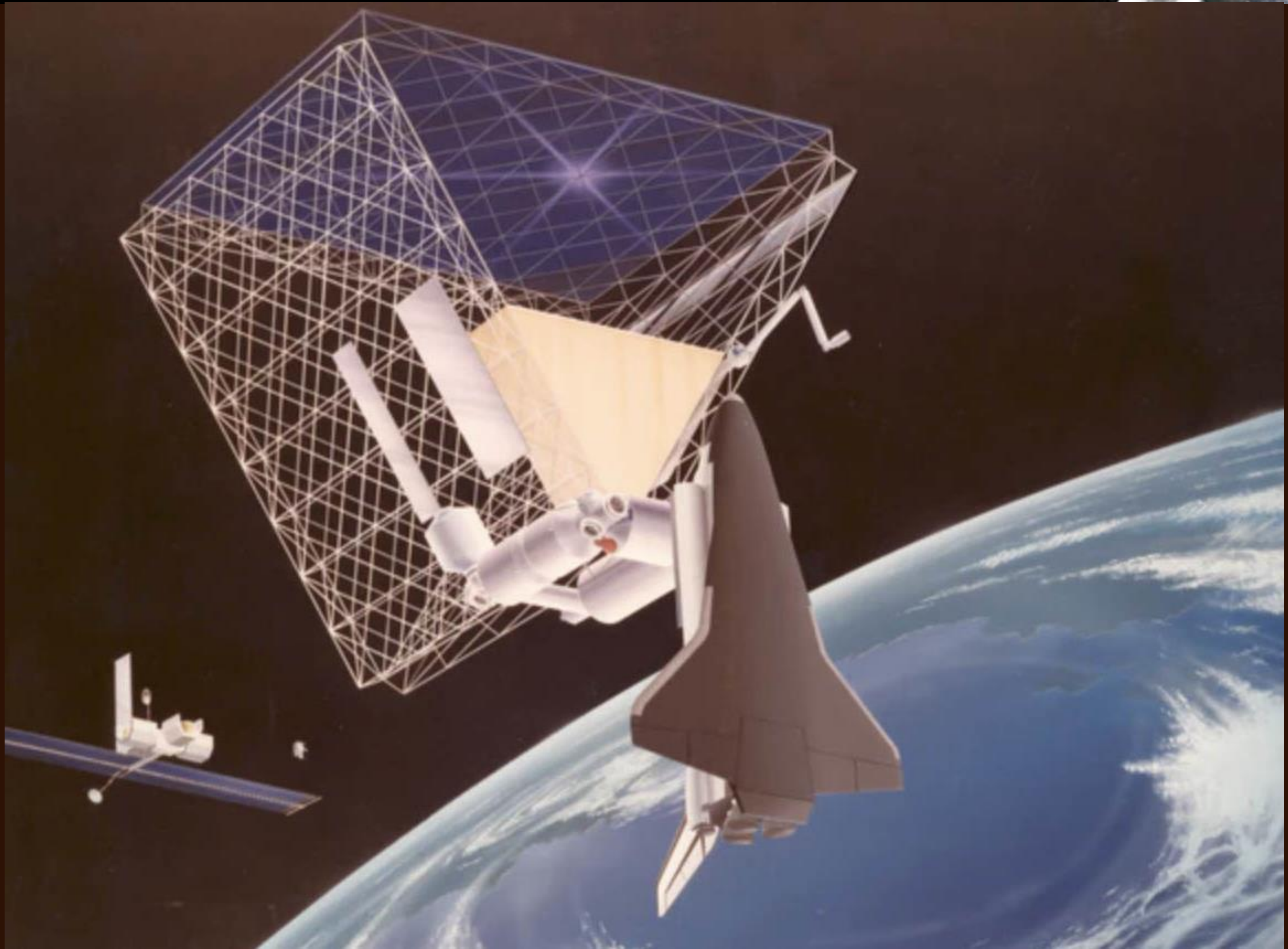
ISS Concepts

~1990

SPACE STATION CONCEPTS

- Before ISS configuration baseline was final, a number of teams proposed concepts
- JSC Structures and Mechanics Division proposed a number of concepts (Wade, Pelischek, Schnieder, Berka, Nagy, Larsen, Hamilton, and others)
  - Triangular station
  - Deployable elements and appendage concepts
  - Maximum number of ground-built elements (utilize experience of Shuttle payloads and robotic spacecraft)
  - All required some EVA
- Numerous other organizations also proposed concepts

TRIANGULAR STATION CONCEPT

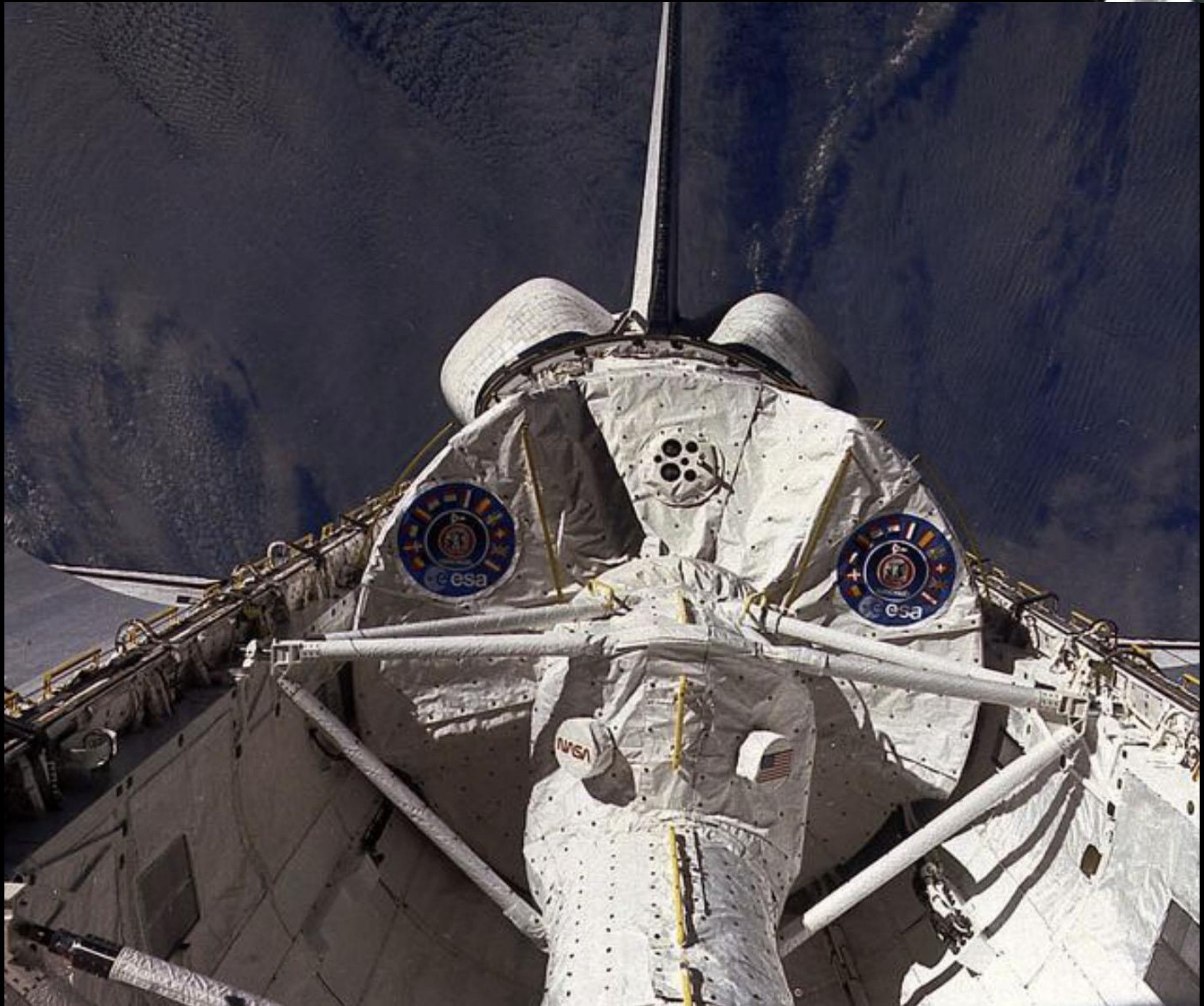


DEPLOYABLE STATION CONCEPT

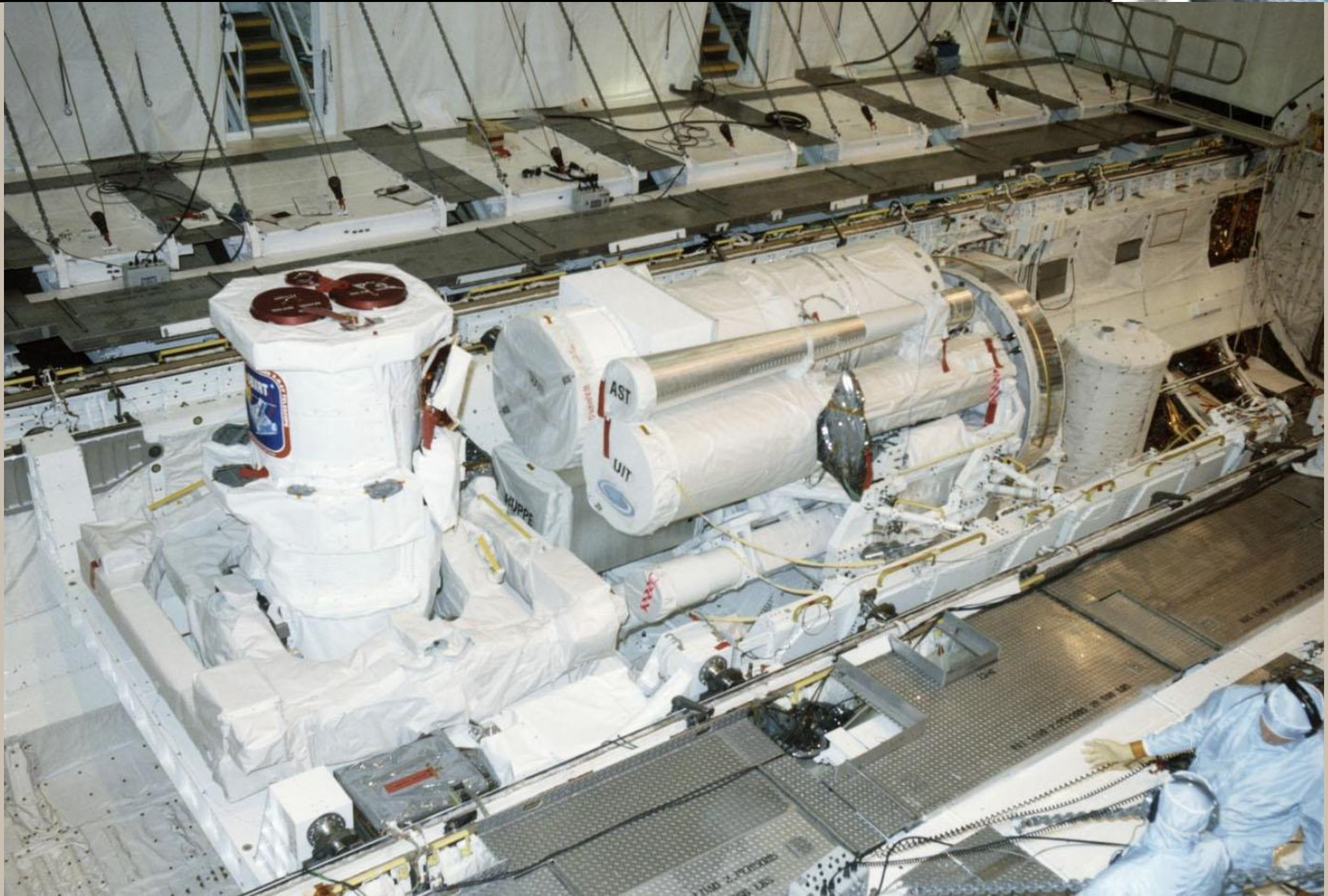
STS PAYLOADS
LEADING TO SPACE STATION

- Shuttle Launched Payloads provided experience applicable to building a Space Station
  - Spacelab module
  - Spacelab Pallets
  - Deployable booms
  - other

SPACELAB MODULE ON STS-9

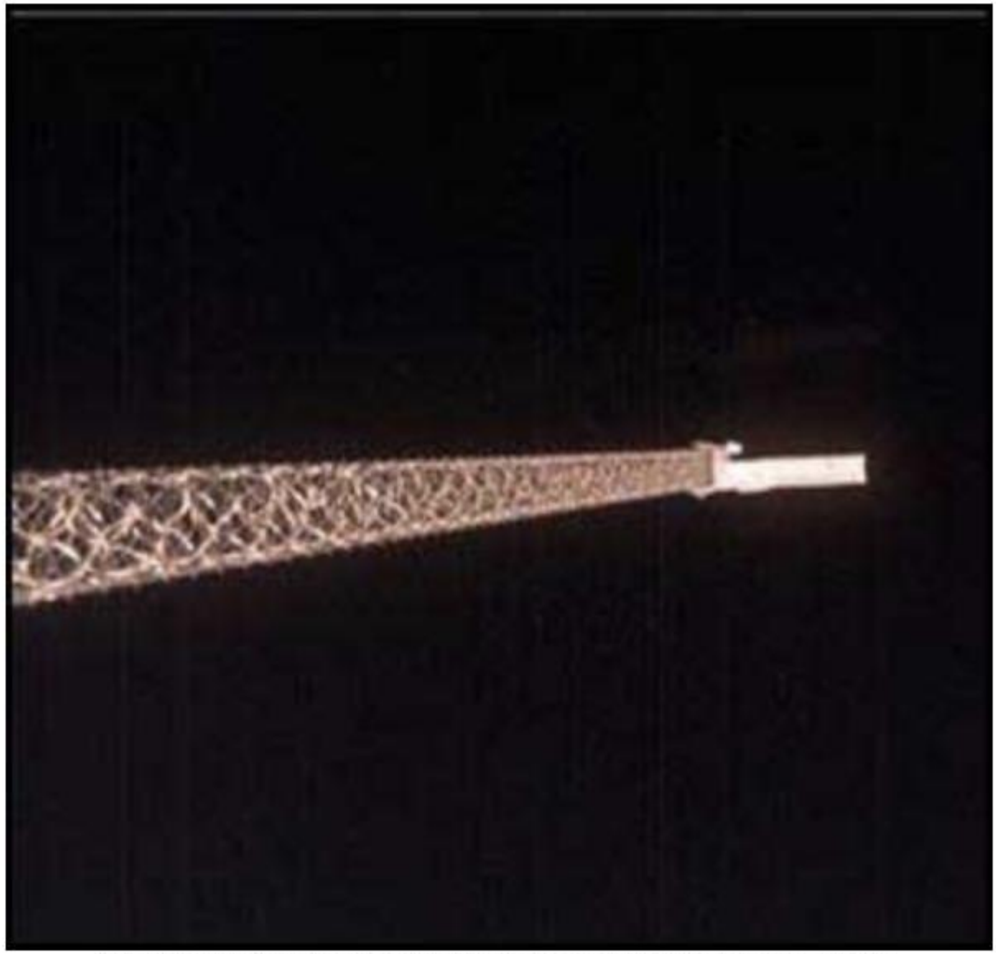


SPACELAB PALLETS



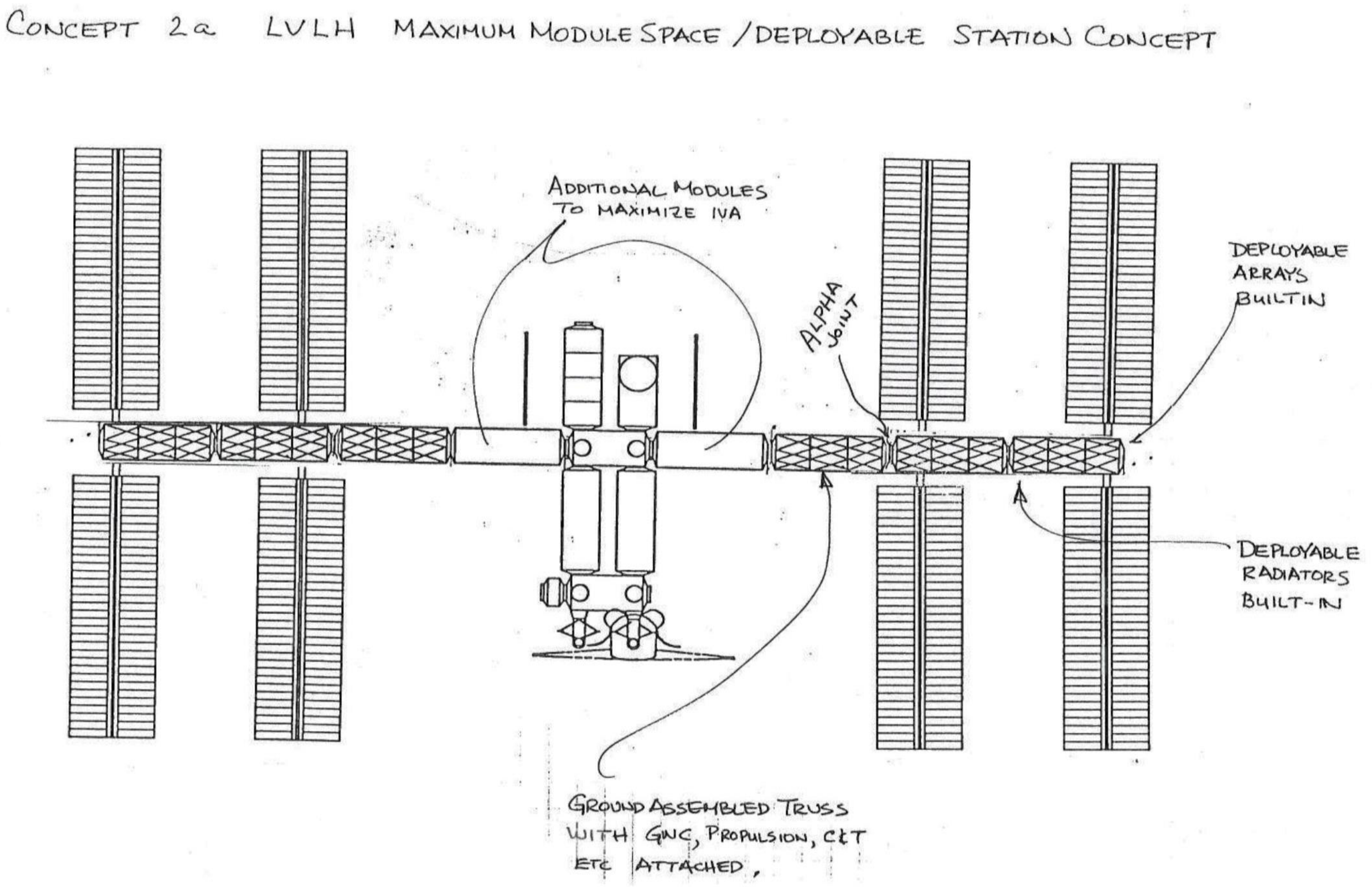
EXTENDABLE BOOM

The first few feet of the mast as photographed from Shuttle Endeavour's aft window

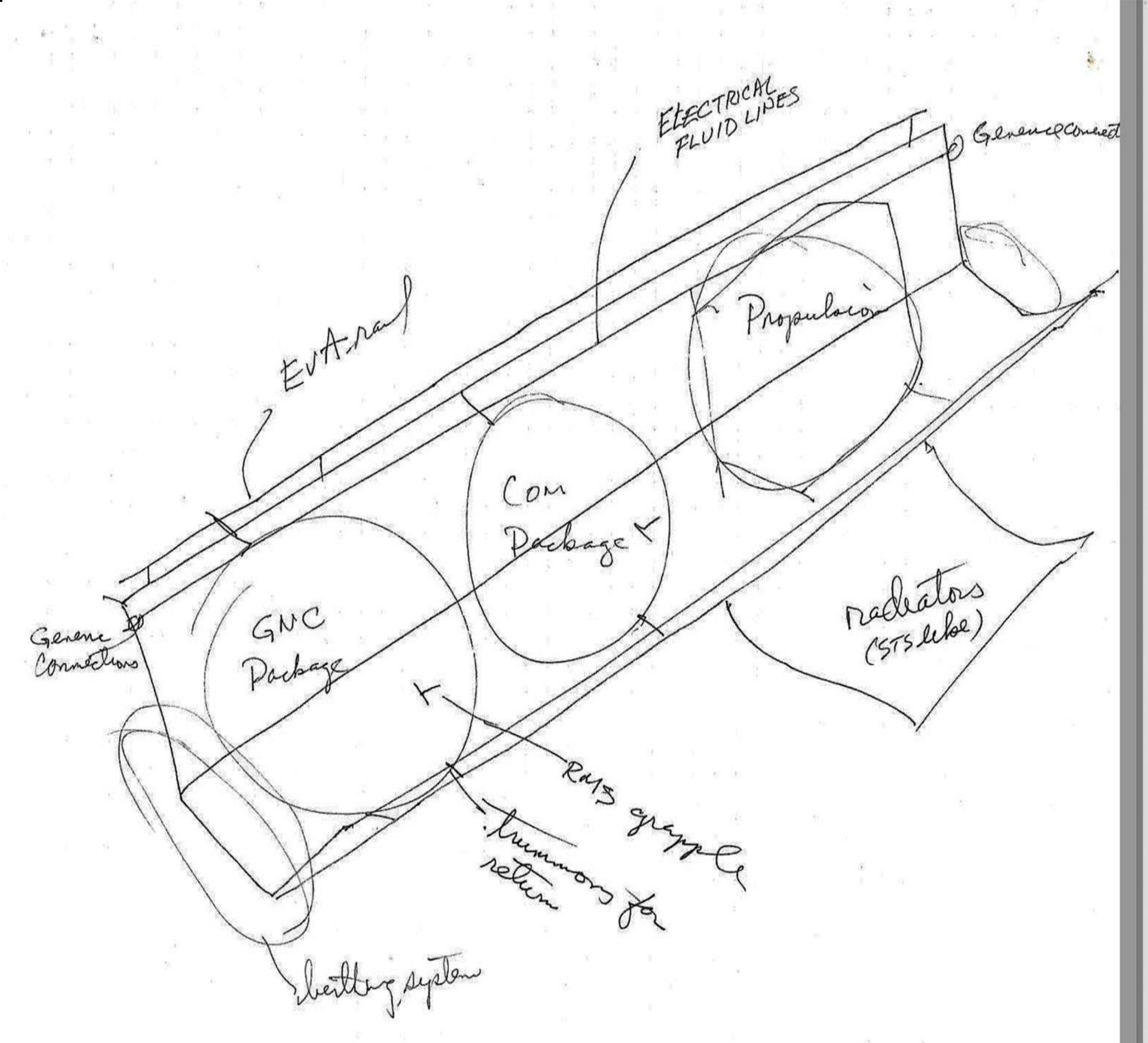


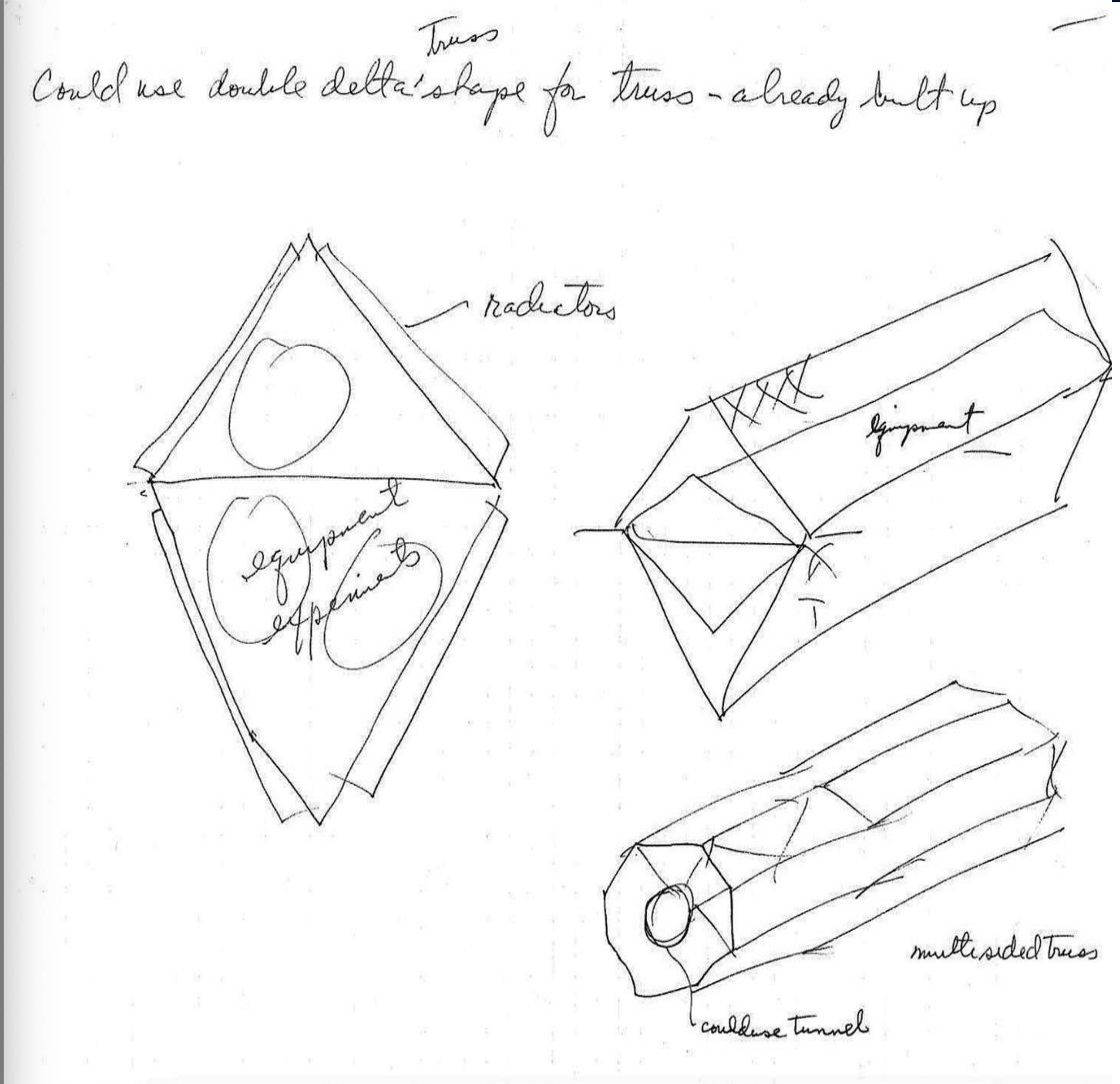
The 60 meter mast with the outboard antenna in space

EARLY SKETCH OF ASSEMBLED ELEMENTS



SKETCHES OF GROUND BUILT ELEMENTS





DAVID HAMILTON TECHNICAL LEADERSHIP EXPERIENCE

- Many valuable jobs that provided opportunity to apply past experience, and to learn from others

David Hamilton Technical Leadership Experience

Many valuable jobs that provided opportunity to apply past experience, and to learn from others

LEADERSHIP POSITIONS

- **Chairman, STS/Payloads Structural/Mechanical Working Group** (8/83 to 1/88). NASA representative to US and international payload developers in area of loads, structures and mechanical systems. Developed design load cases, assessed math model verification approach, provided design guidance, provided input and support to Shuttle Payload Integration Office.
- **Chief of Loads and Dynamics Section** (1/88 to 12/89). Led team of engineers which conducted analyses and test support for define loads requirements, conduct loads and stability analyses, develop mathematical models for simulations, and assess flight and ground test data. Also provided guidance for STS Loads and Dynamics Panel and STS/Payloads Working Group.
- **Chief of the Loads and Structural Dynamics Branch** (12/89 to 7/94). Led team of engineers and technicians conducting dynamic analysis and structural dynamic testing. Analysis group conducted analyses and test support for defining loads requirements, conducting loads and stability analyses, developing mathematical models for simulations, and assessing flight and ground test data. Test group managed and operated the Vibration and Acoustic Test Facility. Branch also provided chairperson for the STS Loads and Dynamics Panel and the STS/Payloads Working Group.

LOADS AND DYNAMICS BRANCH

LEADERSHIP 2

- **Docking System Project Manager** (7/94 to 5/97). Led team of EA and Shuttle contractors which defined Androgynous Peripheral Docking System(APDS) hardware and functional requirements in conjunction with Russian hardware provider, RSC-Energia. Established and maintained schedules, reported to STS and ISS program management, supported hardware development, certification, and delivery, supported flight hardware installation and checkout, supported related flight operation, and supported anomaly resolution.

APDS ON ORBITER AIRLOCK

NASA DOCKING TEAM AT MCC MOSCOW

RED SQUARE ABOUT 1997

LEADERSHIP 3

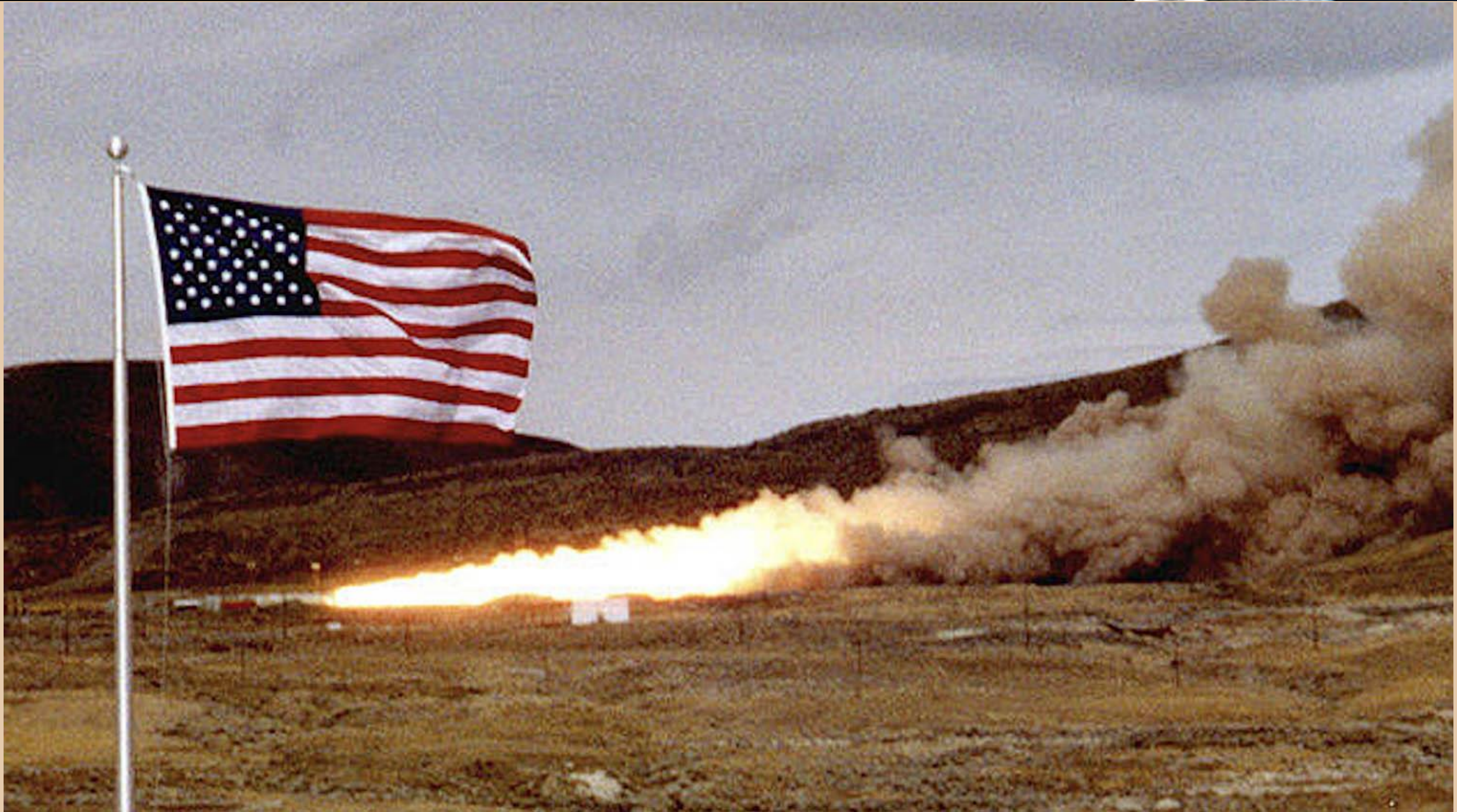
- **Shuttle Chief Engineer** (5/97 to 3/00). Provided technical leadership and support to the Orbiter Vehicle Office and Shuttle Program Office. Served as NASA Chairman of the Orbiter Review Board, which provided technical evaluation, guidance to NASA and Orbiter contractor on design or process changes and issue resolution. Also served as Engineering Directorate representative to Orbiter Project change board.
- **Manager, Shuttle Station Engineering Office** (3/00 to 10/03). Manage STS, ISS, and GFE branches providing Chief Engineers, systems engineering/integration, and analysis support to STS and ISS Programs. Represent Engineering Directorate at STS and ISS Program Control Boards(PRCB&SSCB). Served as chairman of STS Chief Engineers Council and member of the STS Program Managers Council.

SHUTTLE CHIEF ENGINEERS AT SSC

Chief Engineer Council Members

Len Worland
John Chapman
Steve Cash
Dan Adamsky
David Hamilton
Gale Copeland
Charlie Abner
Bob Herman
Paul Shack
Neil Otte
Bob Lang
David Wood

SRM TEST AT ATK



ATLANTIS OMDP AT PALMDALE

LEADERSHIP POSITIONS 4

- **NESC Chief Engineer, JSC** (7/03 thru 8/07)
- Represented the NASA NESC at JSC. Support SSP, ISS and Constellation Program by providing technical insight, guidance, and support from NESC.
- Represented NESC at Program decision boards, at flight readiness, and in-flight activities.
- Developed initial assessment of technical issues for presentation to the NESC Review Board.
- Provided technical and management insight/background to broader

NESC TEAM IN WILLIAMSBURG 2005

LAST ORBITER LANDING, 2011

SHUTTLE IN REVIEW MIRROR

ORBITER ATLANTIS PAYLOAD BAY 2023