PERFORMANCE ASSESSMENT OF AERO-ASSISTED ORBITAL TRANSFER VEHICLES

Richard W. Powell, Theodore A. Talay, Alan W. Wilhite
John J. Rehder, Nancy H. White, J. Chris Naftel, Howard W. Stone,
James P. Arrington, and Ronald S. McCandless
NASA Langley Research Center

The NASA Langley Research Center is performing analyses of aero-assisted orbital transfer vehicles. The studies to date have been to determine the aerodynamic characteristics over the flight profile and three- and six-degree-of-freedom performance analyses.

The important results, to date, are: 1) The Aerodynamic Preliminary Analysis System, an interactive computer program, can be used to predict the aerodynamics (performance, stability, and control) for these vehicles; 2) the performance capability, e.g. maximum inclination change, maximum heating rate, and maximum sensed acceleration, can be determined using continuum aerodynamics only; 3) guidance schemes can be developed that allow for errors in atmospheric density prediction, mispredicted trim angle of attack, and off-nominal atmospheric interface conditions, even for vehicles with a low lift-to-drag ratio; and 4) multiple pass trajectories can be used to reduce the maximum heating rate.

FLIGHT PROFILES

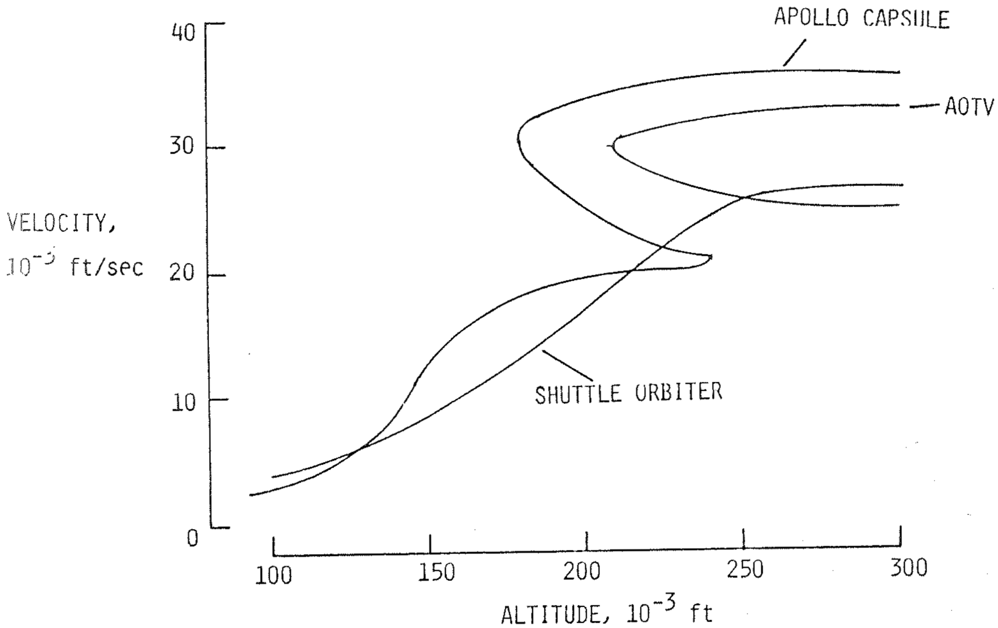

Figure 1

AOTV CONFIGURATION FOR LOW LIFT/DRAG

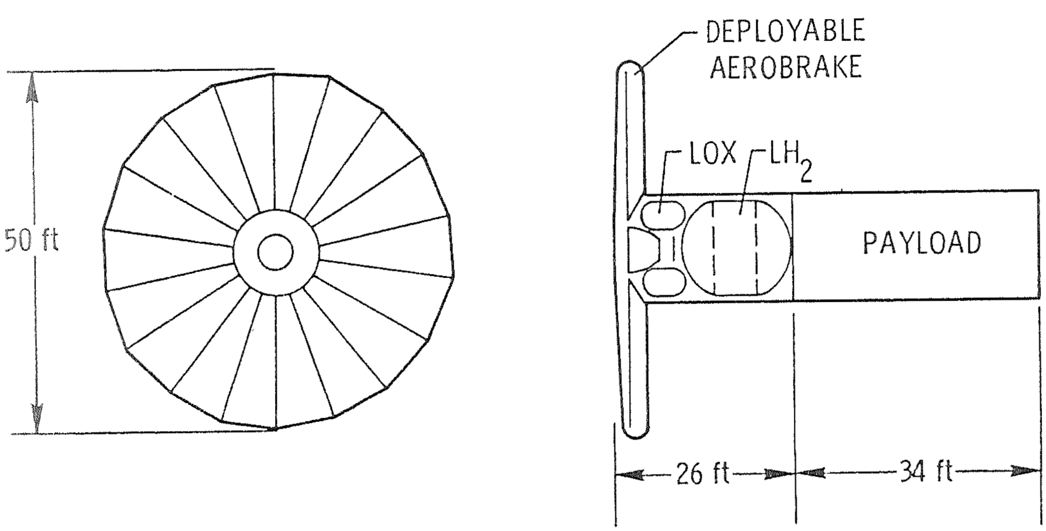

Figure 2

LOW L/D CONCEPT PERFORMANCE AERODYNAMICS

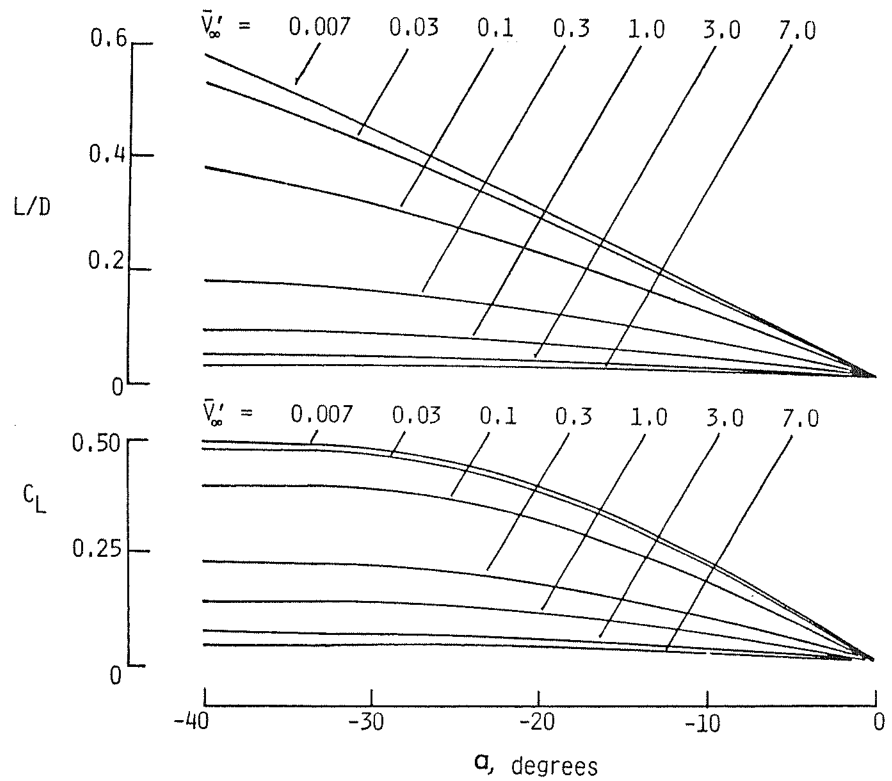

Figure 3

AOTV CONFIGURATION FOR MEDIUM LIFT/DRAG

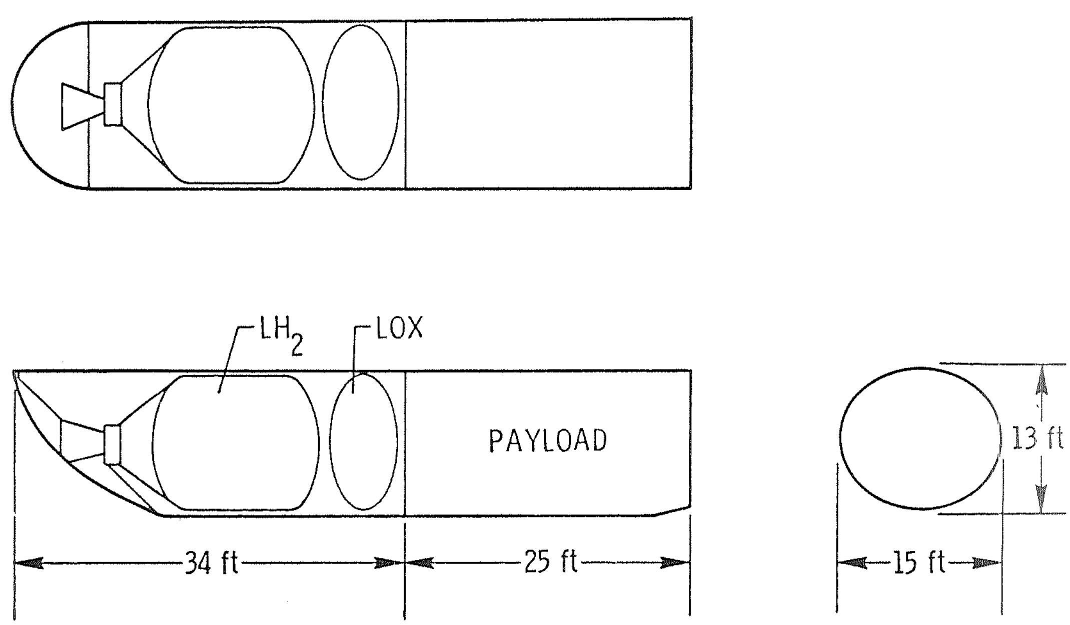

Figure 4

MID L/D CONCEPT PERFORMANCE AERODYNAMICS

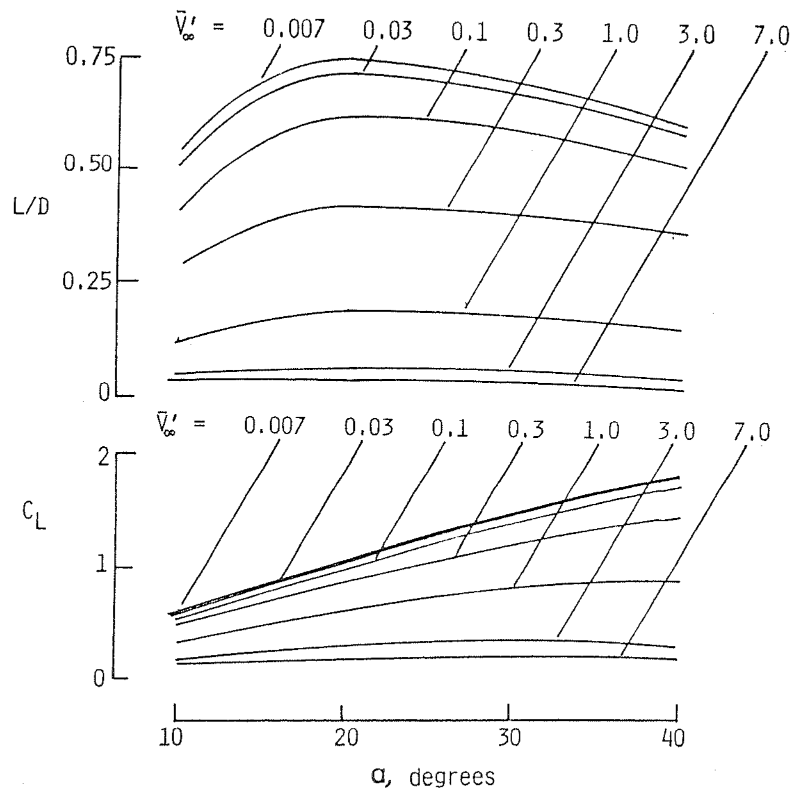

Figure 5

AOTV CONFIGURATION FOR HIGH LIFT/DRAG

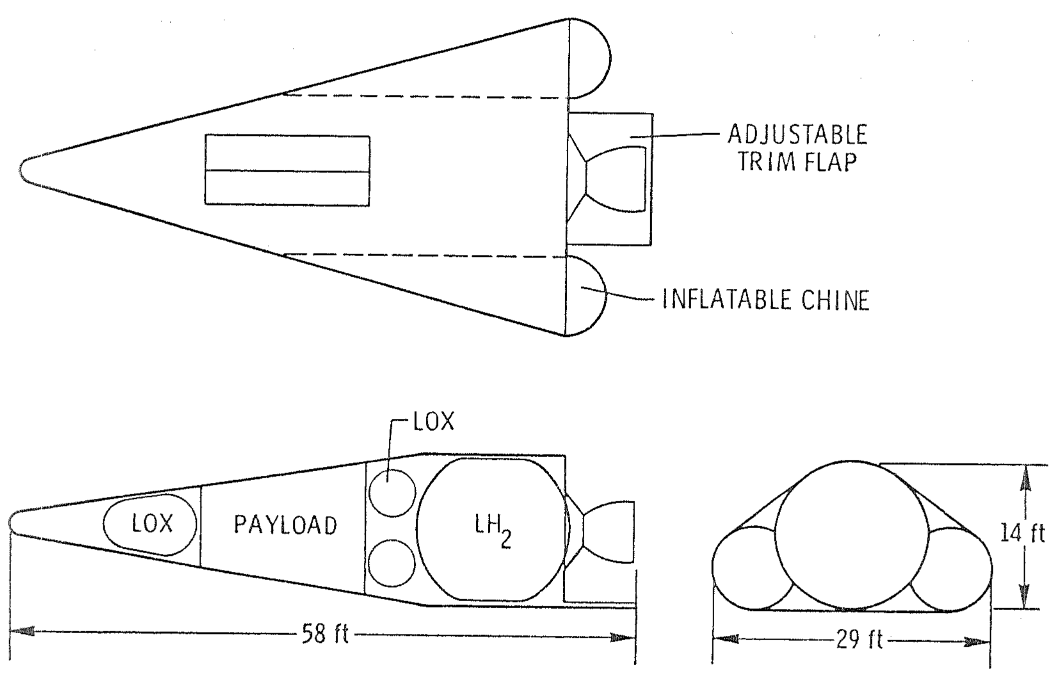

Figure 6

HIGH L/D PERFORMANCE AERODYNAMICS

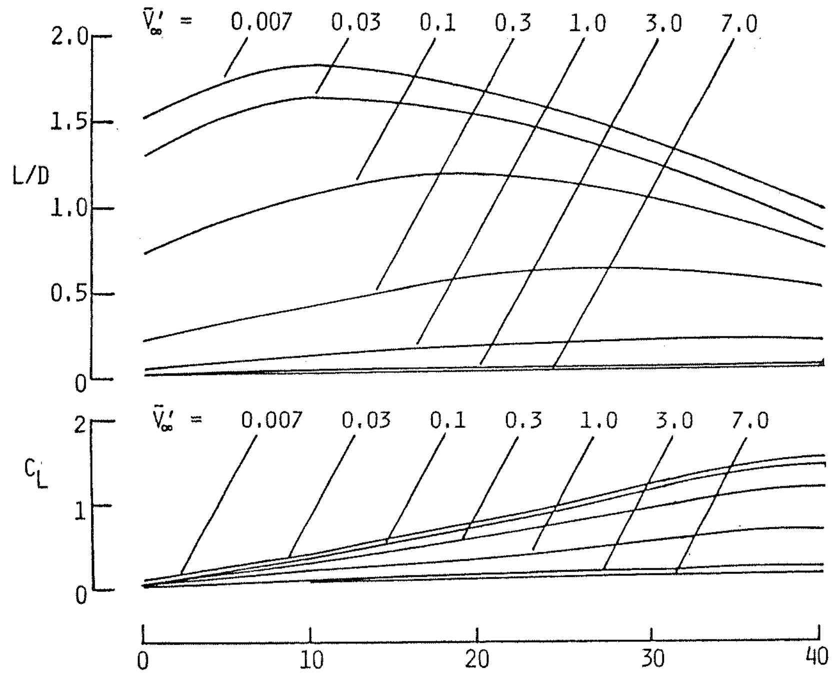

Figure 7

AOTV L/D PERFORMANCE COMPARISON

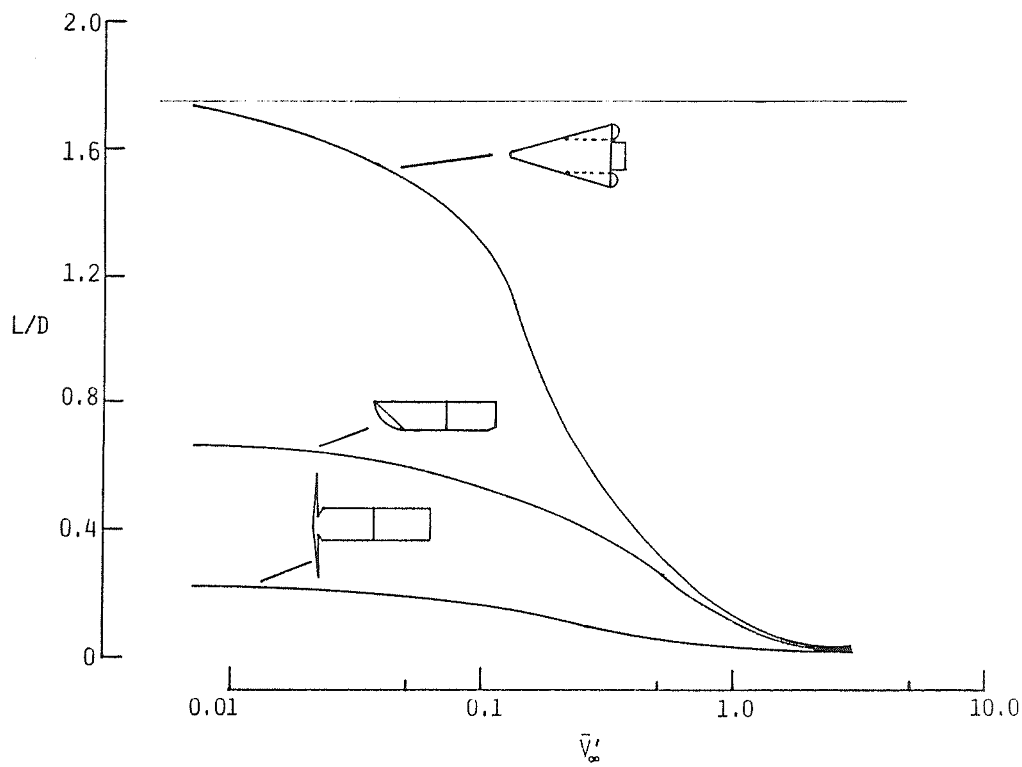

Figure 8

GEOSYNCHRONOUS ORBIT MISSION USING AN AEROASSISTED TRANSFER VEHICLE

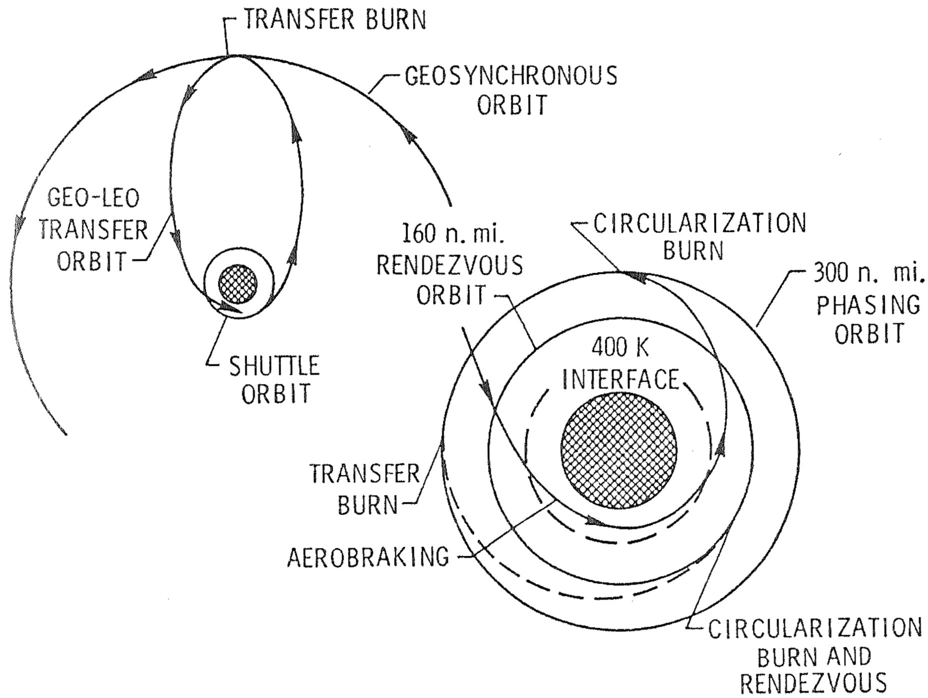

Figure 9

ANALYSIS TECHNIQUE

- o 3-D PROGRAM TO OPTIMIZE SIMULATED TRAJECTORIES (POST)
- o GEO-LEO TRANSFER——TIMING, DURATION, ANGLE
- o ATMOSPHERIC PASS——400,000 FT INTERFACE (1962 U.S. STANDARD)
  - o ALL VEHICLES HAVE A LIFT CAPABILITY
  - o MAINTAIN CONSTANT ANGLE OF ATTACK DURING PASS
  - o ROLL VEHICLE ABOUT VELOCITY VECTOR TO VARY LIFT DIRECTION
  - o TARGET TO 300 NMI PHASING ORBIT, 28.5° INCLINATION, SAME LONGITUDE OF ASCENDING NODE AS SHUTTLE
  - o 3-BURN PROPULSIVE SEQUENCE LEADS AOTV TO RENDEZVOUS WITH SHUTTLE ORBITER

Figure 10

ALTITUDE HISTORIES FOR MAXIMUM RETURN WEIGHT AOTV'S

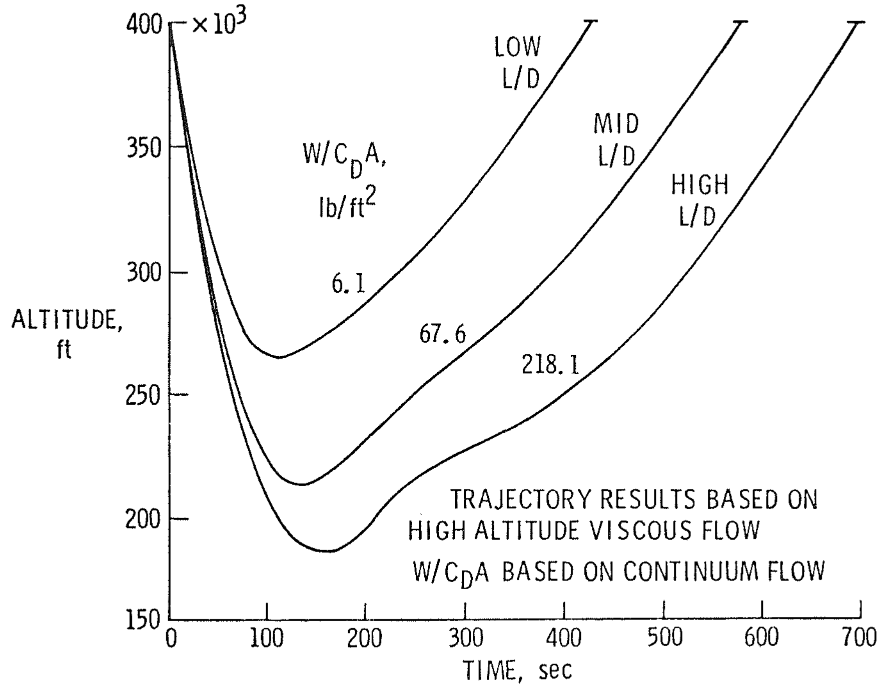

Figure 11

ORBIT INCLINATION HISTORIES FOR MAXIMUM RETURN WEIGHT AOTV'S

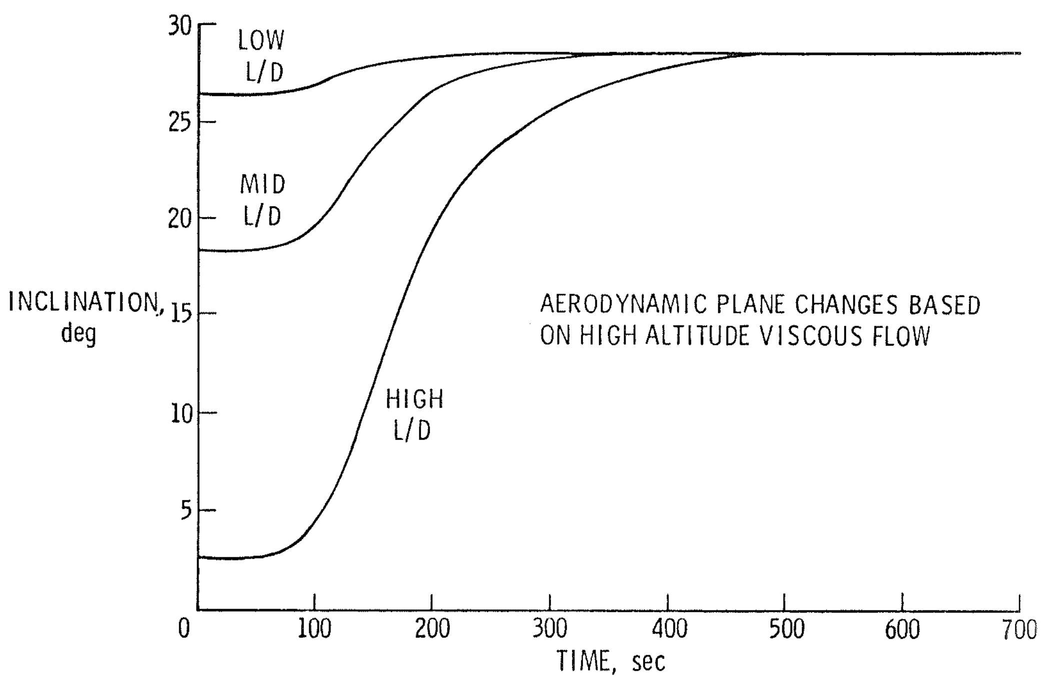

Figure 12

DYNAMIC PRESSURE HISTORIES FOR MAXIMUM RETURN WEIGHT AOTV'S

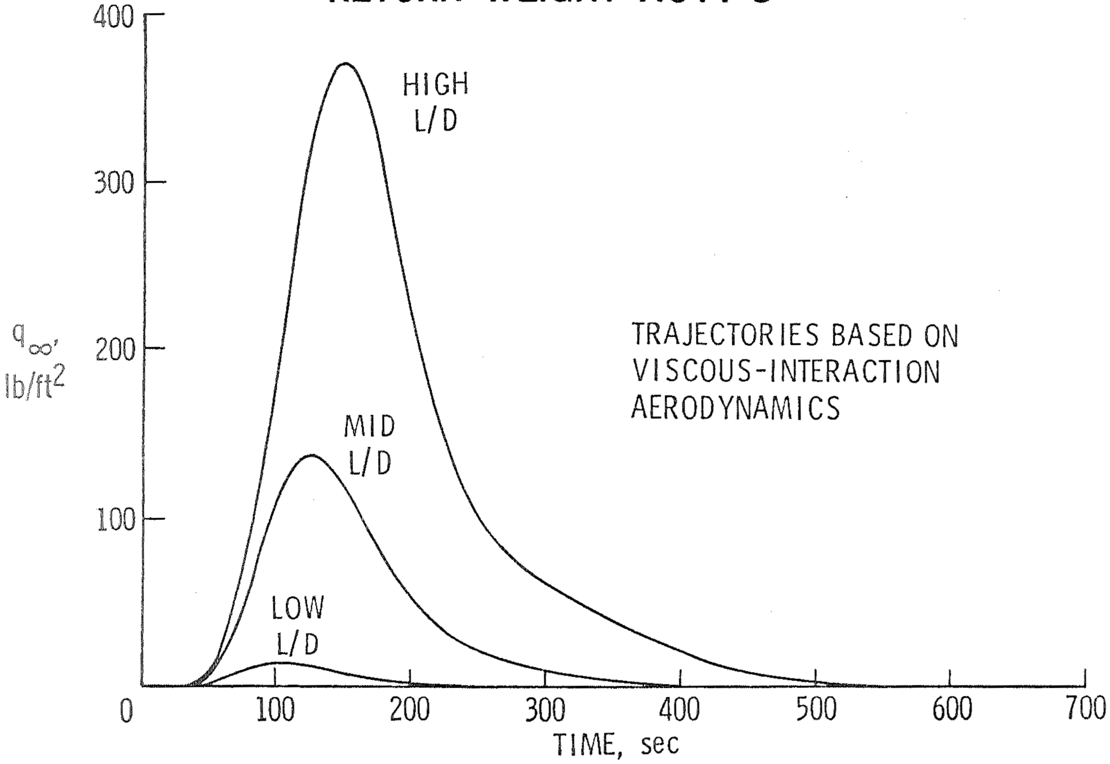

Figure 13

ACCELERATION HISTORIES FOR MAXIMUM RETURN WEIGHT AOTV'S

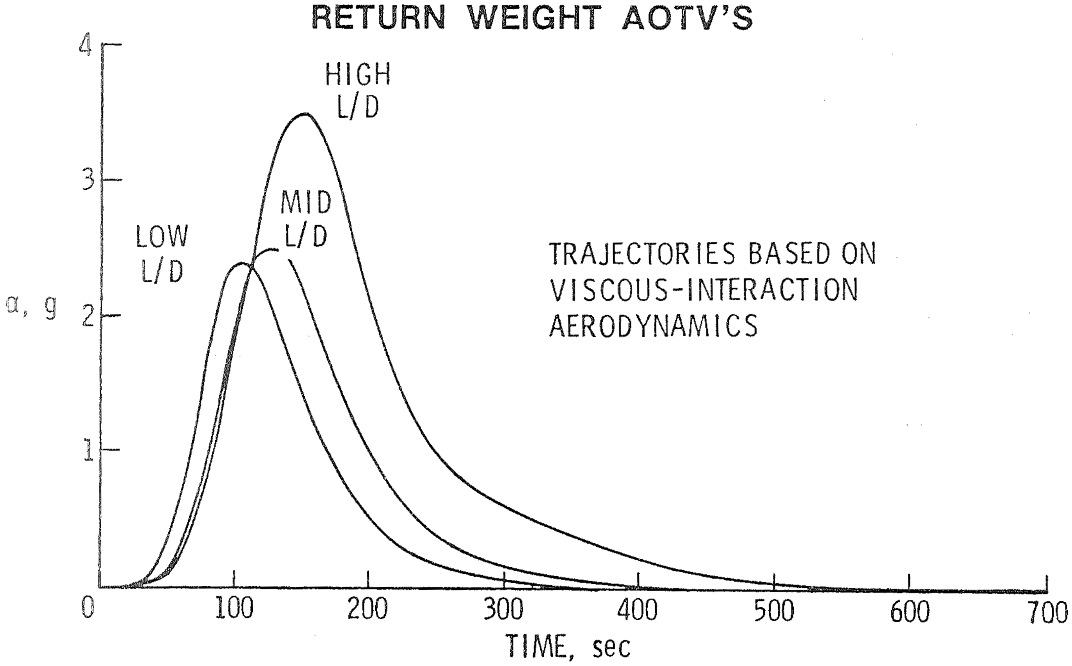

Figure 14

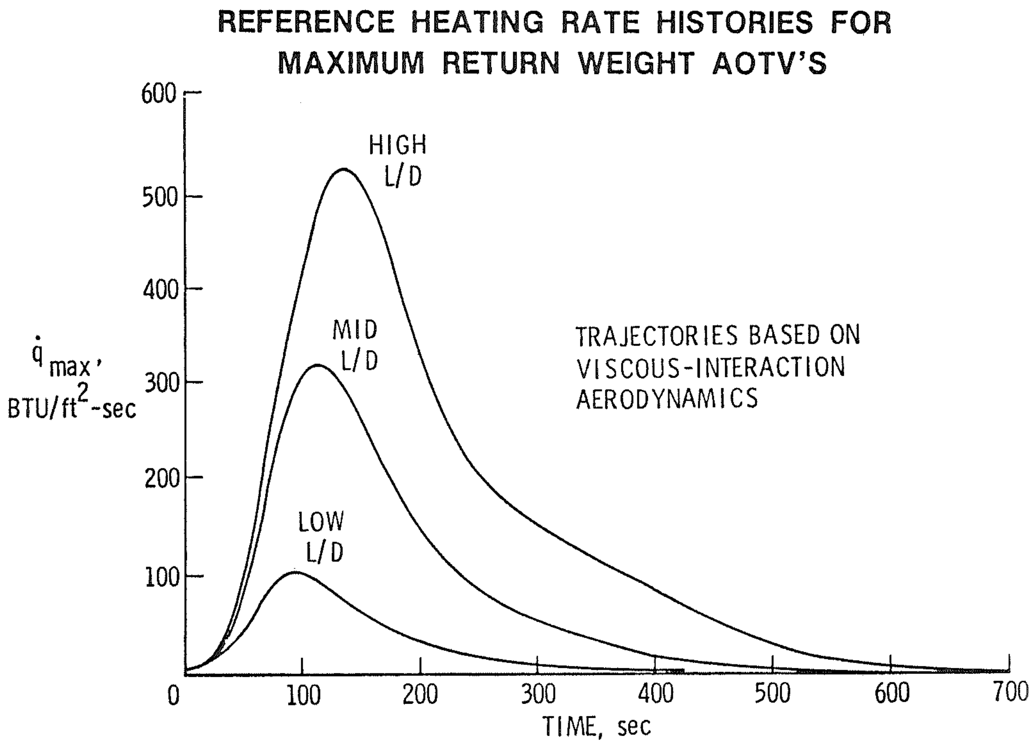

Figure 15

PERFORMANCE COMPARISON OF AN ALL-PROPULSIVE OTV
WITH AOTV's FOR GEO ROUND-TRIP MISSIONS

OTV TYPE	ALL PROPULSIVE	LOW L/D	MID L/D	HIGH L/D
INITIAL WEIGHT, LB	66,000	66,000	66,000	66,000
WEIGHT RETURNED TO SHUTTLE, LB	9,666	15,833	16,396	16,987
MAXIMUM STAGNATATION POINT HEATING RATE TO A 1 FOOT RADUS SPHERE, BTU/FT^2 -SEC		102	317	372
MAXIMUM SENSED ACCELERATION, G'S		2.40	2.51	3.50

Figure 16

LIFT/DRAG HISTORIES OF MAXIMUM RETURN WEIGHT AOTV'S

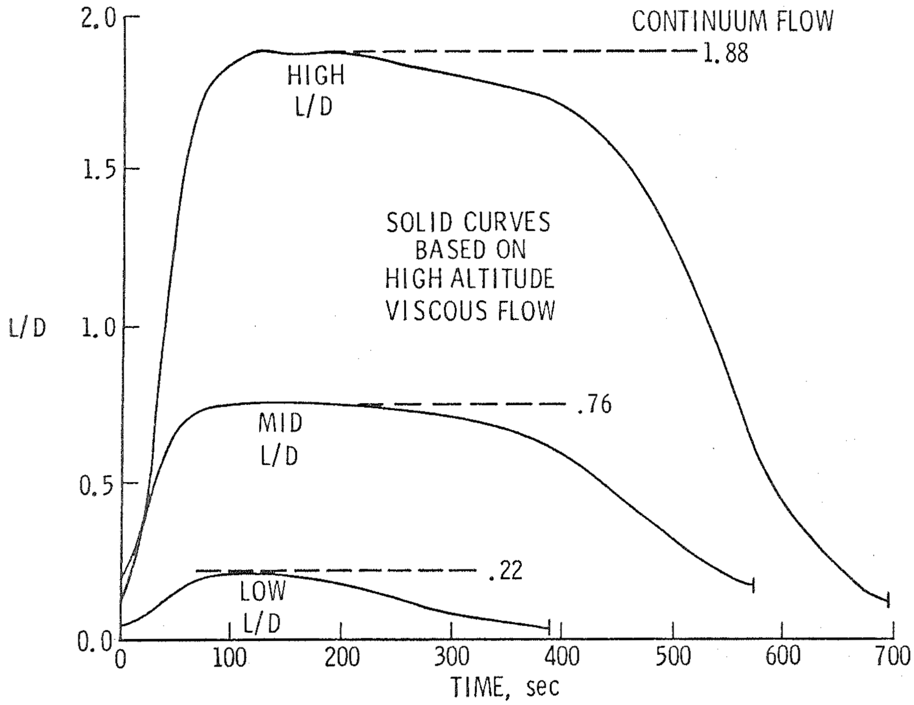

Figure 17

AOTV WEIGHT RETURNED TO SHUTTLE

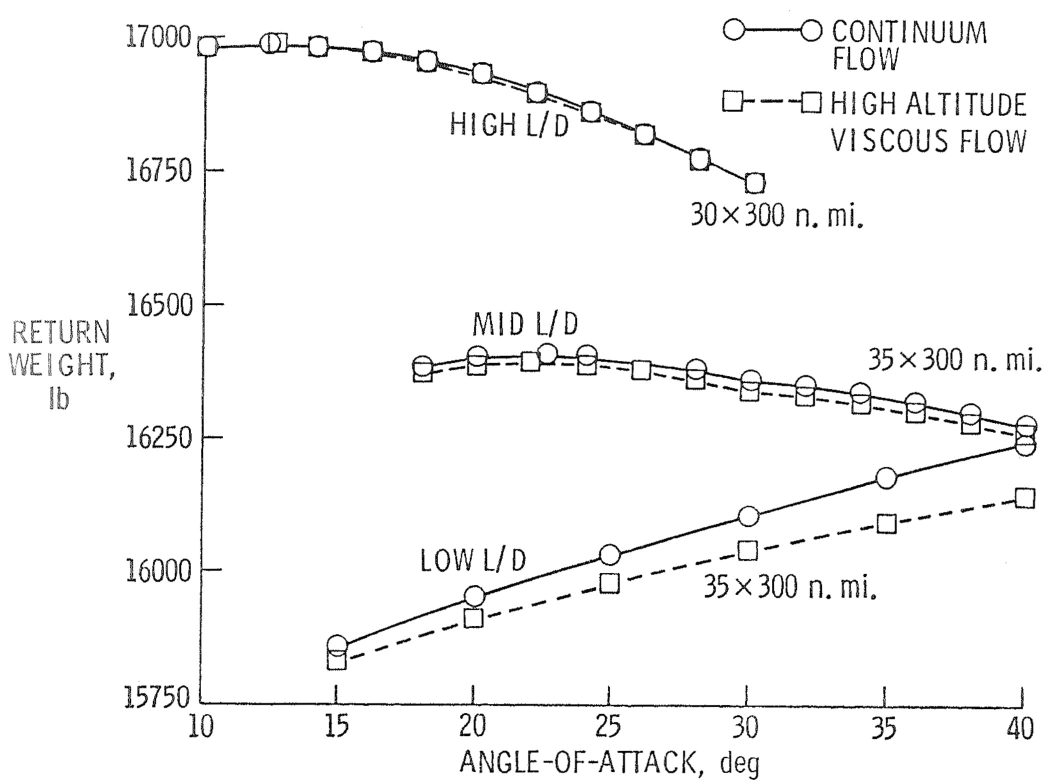

Figure 18

SIX-DEGREE-OF-FREEDOM SIMULATION ANALYSIS

ANALYSIS UNDERTAKEN TO:

1) SIZE THE REACTION CONTROL SYSTEM (RCS)

2) EVALUATE GUIDANCE ALGORITHMS

3) CONFIRM THREE-DEGREE-OF-FREEDOM ANALYSIS

CONTROL SYSTEM DESIGNED UTILIZED RCS ONLY

THREE GUIDANCE ALGORITHMS EVALUATED

1) PREDICTIVE TECHNIQUE

2) DRAG REFERENCE ALGOTITHM DERIVED BY OLIVER HILL OF NASA-JSC

3) REFERENCE ORBITAL ENERGY - FLIGHT PATH ANGLE REFERENCE ALGORITHM

Figure 19

LOW L/D CONFIGURATION RESPONSE CHARACTERISTICS

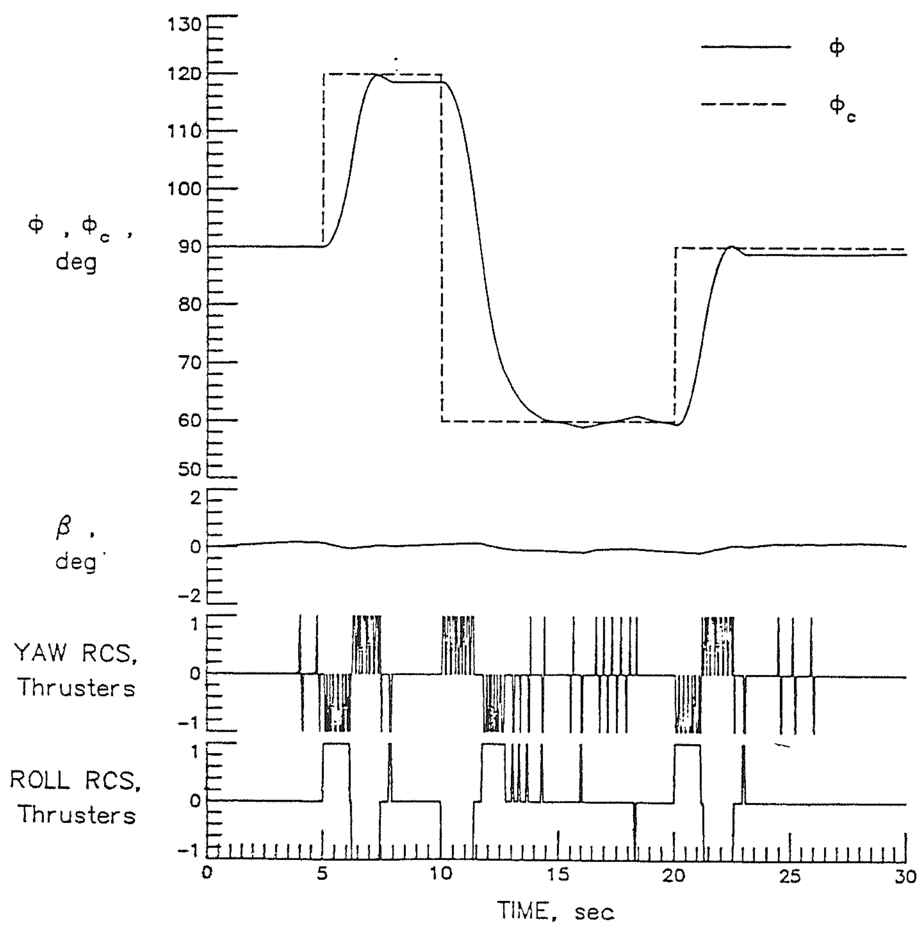

Figure 20

GUIDANCE ALGORITHM

- O AOTV IS COMMANDED TO FLY THE OPTIMUM ORBITAL ENERGY VS INERTIAL FLIGHT PATH ANGLE PROFILE THAT HAD BEEN DETERMINED FROM A 3 DEGREE-OF-FREEDOM ANALYSIS
- O AOTV IS COMMANDED TO FLY CONSTANT ANGLE OF ATTACK
- O INCLINATION IS CONTROLLED BY ROLL REVERSALS

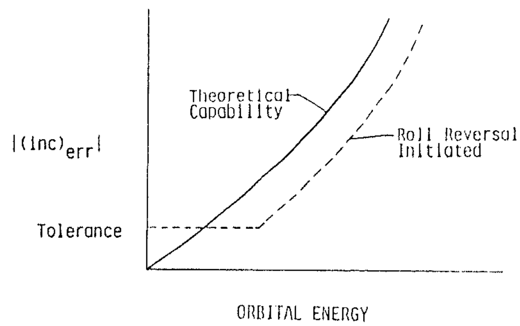

Figure 21

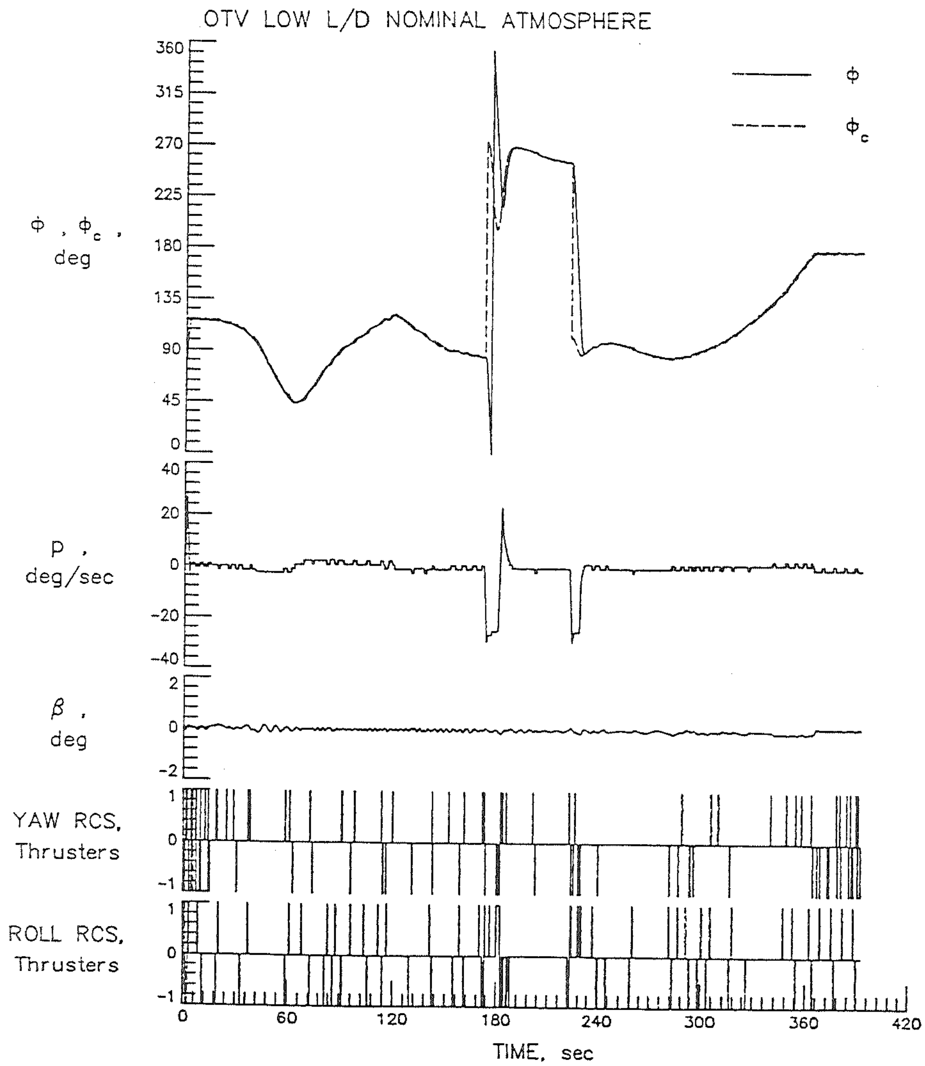

Figure 22

SHUTTLE-DERIVED ALTITUDE-DENSITY PROFILES

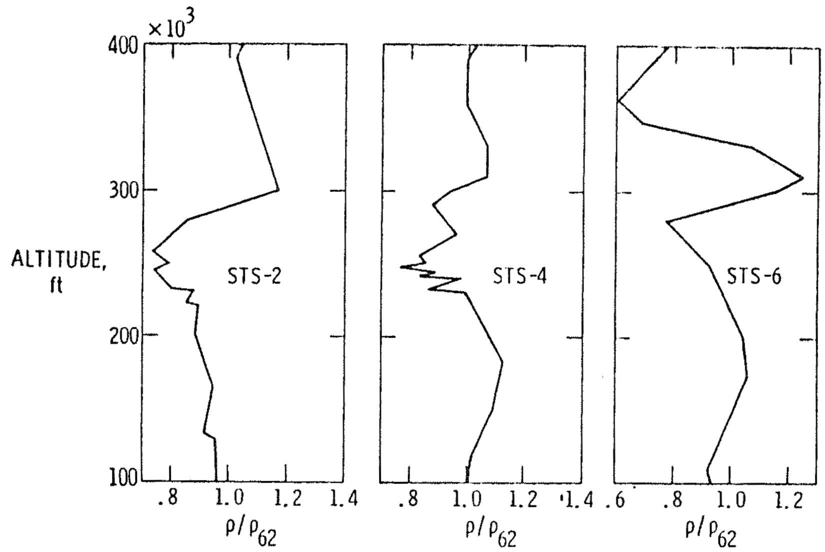

Figure 23

OTV LOW L/D NOMINAL ATMOSPHERE

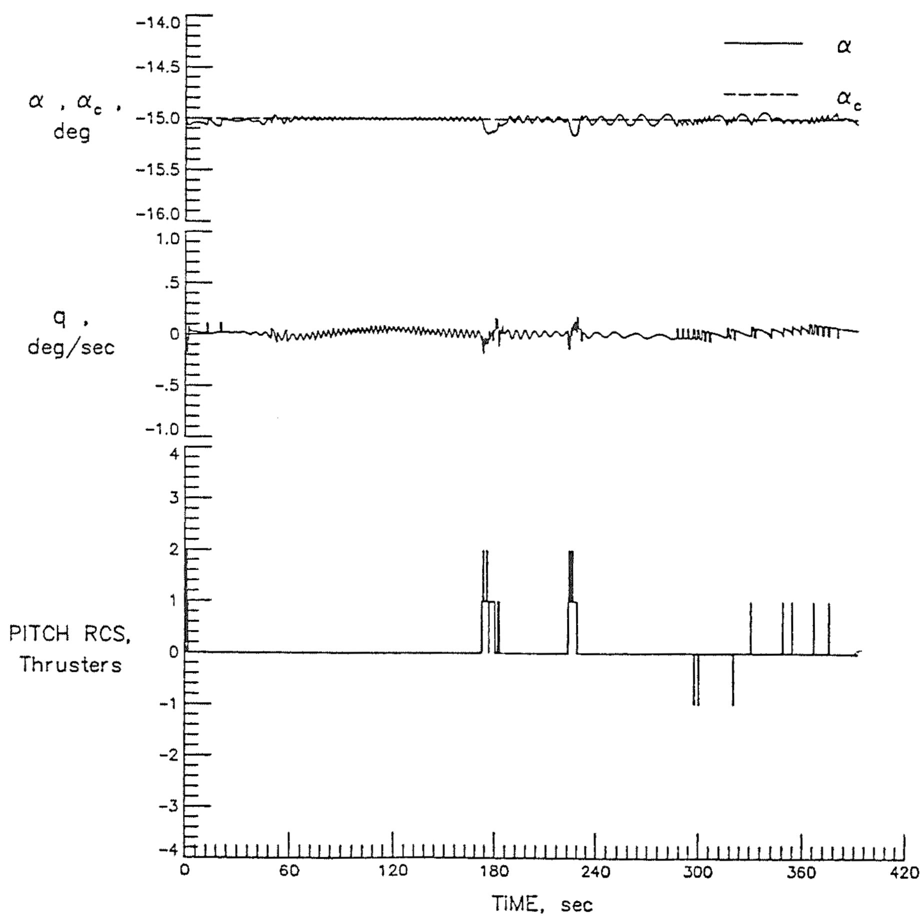

Figure 24

COMPARISON OF ATMOSPHERIC PASS FOR LOW L/D CONFIGURATION

	ATMOSPHERES					
	1962 STANDARD	+25%	-25%	STS-2	STS-4	STS-6
EXIT APOGEE, NMI	306	287	323	313	311	314
EXIT PERIGEE, NMI	34	31	35	35	35	35
EXIT INCLINATION, DEG	28.5	28.5	28.5	28.5	28.5	28.5
TOTAL ATMOSPHERIC PASS TIME, SEC	392	380	407	408	399	411
PITCH RCS ON-TIME, SEC	19.44	22.48	24.44	18.72	19.96	28.00
ROLL RCS ON-TIME, SEC	18.16	22.28	20.72	18.56	18.68	20.92
YAW RCS ON-TIME, SEC	20.08	23.60	24.48	21.76	21.2	29.84

Figure 25

COMPARISON OF ATMOSPHERIC PASS FOR LOW L/D CONFIGURATION

	TRIMMED ANGLE-OF-ATTACK VARIATIONS						
	$\alpha_T = \alpha_D$	$\alpha_T = \alpha_D - 1$	$\alpha_T = \alpha_D + 1$	$\alpha_T = \alpha_D - 3$	$\alpha_T = \alpha_D + 3$	$\alpha_T = \alpha_D - 5$	$\alpha_T = \alpha_D + 5$
EXIT APOGEE, NMI	306	309	305	295	301	297	300
EXIT PERIGEE, NMI	34	34	34	32	33	32	33
EXIT INCLINATION, DEG	28.5	28.5	28.5	28.5	28.5	28.5	28.1
TOTAL ATMOSPHERIC PASS TIME, SEC	392	393	392	393	390	393	389
PITCH RCS ON-TIME, SEC	19.44	23.52	17.16	29.52	3.20	36.40	2.36
ROLL RCS ON-TIME, SEC	18.16	20.48	17.84	19.84	12.28	24.08	11.08
YAW RCS ON-TIME, SEC	20.08	26.32	18.56	29.84	14.0	36.48	17.68

Figure 26

COMPARISON OF ATMOSPHERIC PASS FOR LOW L/D CONFIGURATION

	ENTRY FLIGHT PATH ANGLE VARIATIONS						
	$\gamma_I = \gamma_D$	$\gamma_I = \gamma_D - .05$	$\gamma_I = \gamma_D - .05$	$\gamma_I = \gamma_D - .1$	$\gamma_I = \gamma_D + .1$	$\gamma_I = \gamma_D - .2$	$\gamma_I = \gamma_D + .2$
VACUUM PERIGEE, NMI	45.4	44.9	45.9	44.4	46.4	43.4	47.3
EXIT APOGEE, NMI	306	298	312	263	326	156	394
EXIT PERIGEE, NMI	34	32	35	27	36	-8	40
EXIT INCLINATION, DEG	28.5	28.5	28.5	28.4	28.5	28.5	28.5
TOTAL ATMOSPHERIC PASS TIME, SEC	392	389	394	382	398	369	406
PITCH RCS ON-TIME, SEC	19.44	21.56	23.48	21.68	23.12	15.76	13.72
ROLL RCS ON-TIME, SEC	18.16	19.32	18.72	17.68	19.24	27.36	13.92
YAW RCS ON-TIME, SEC	20.08	22.72	22.32	23.44	18.4	22.4	13.04

Figure 27

COMPARISON OF AOTV TRAJECTORIES

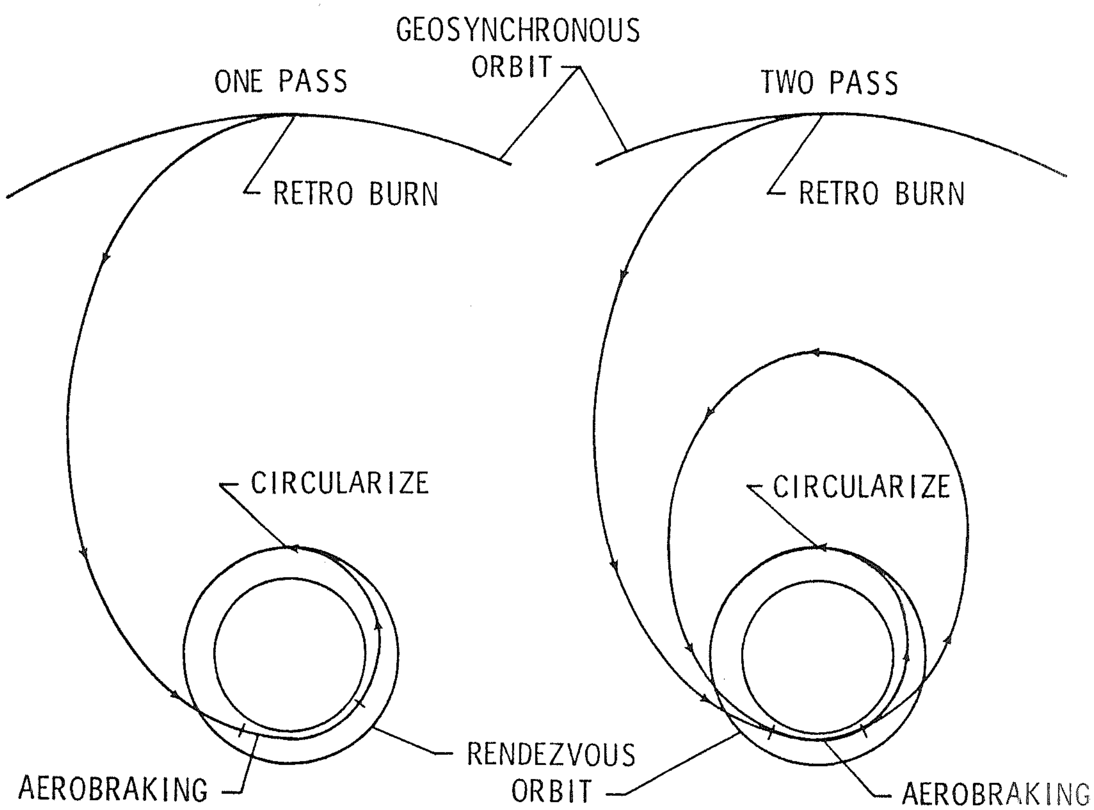

Figure 28

EFFECT OF NUMBER OF PASSES ON HEAT RATE

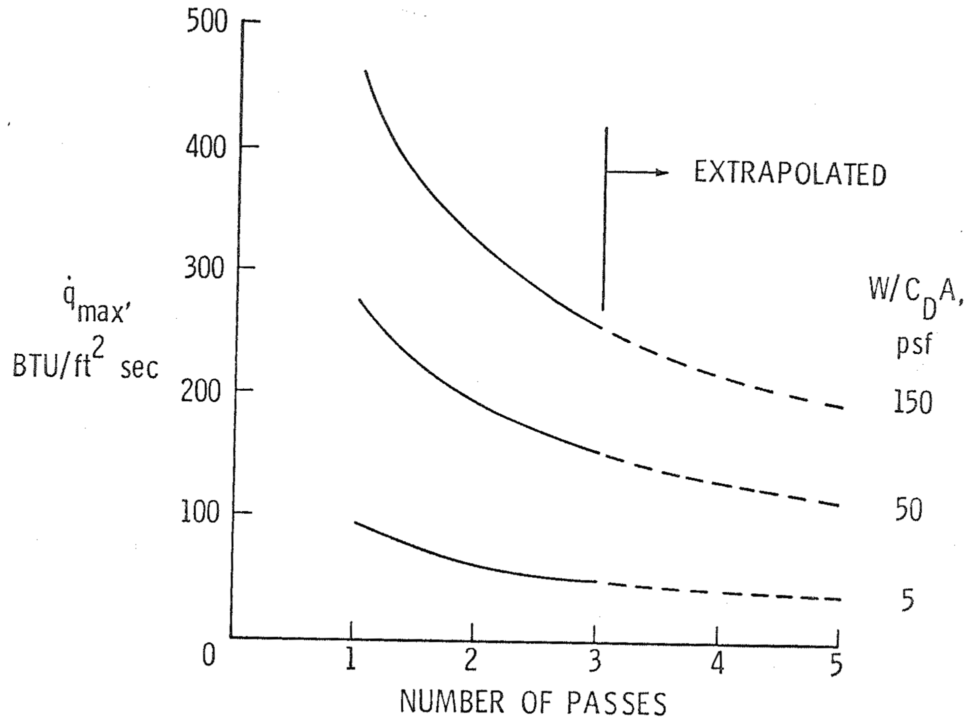

Figure 29

CONCLUSIONS

- APAS IS APPLICABLE FOR AOTV's AND CAN BE USED TO PREDICT AERODYNAMICS FROM THE FREE MOLECULAR FLOW REGION TO THE CONTINUUM REGION
- THREE DoF ANALYSIS SHOWED THAT CONTINUUM AERODYNAMICS IS ADEQUATE FOR PERFORMANCE EVALUATION
- SIX DoF ANALYSIS SHOWED CAPABILITY TO TOLERATE OFF-NOMINAL ATMOSPHERIC DENSITY PROFILES, MISS-PREDICTIVE TRIM ANGLE-OF-ATTACK, AND OFF-NOMINAL ATMOSPHERIC INTERFACE CONDITIONS
- MULTI-PASS TRAJECTORIES OFFER POTENTIAL TO REDUCE MAXIMUM HEATING RATES

Figure 30