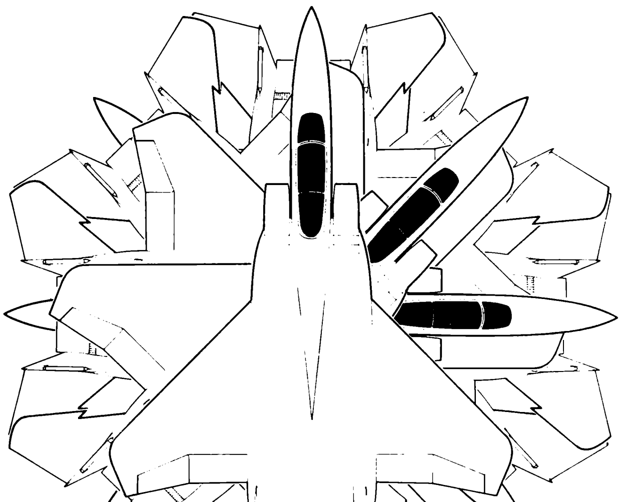
F-15 SPIN WORKSHOP

NASA Dryden Flight Research Center

Edwards, California



May 20, 1976

AGENDA

8:30 Welcome - Gerald Griffin, NASA Dryden Flight Research Center

8:40 Opening Remarks - Ken Iliff, NASA Dryden Flight Research Center

8:50 F-15 Design Philosophy and movie showing four F-15 spin testing programs - Skip Hickey, USAF Aeronautical Systems Div.

9:15 Individual Presentations

Design and Predictions for F-15 - John Mello, McDonnell-Douglas Corp.

Spin Tunnel and Helicopter Drop Model Tests - Jim Bowman, NASA Langley Research Center

10:15 Break

Remotely Piloted 3/8-Scale Model Test and Research - Ken Iliff, NASA Dryden Flight Research Center

Full Scale F-15 Spin Tests - Don Wilson, Air Force Flight Test Center

11:45 Lunch

1:00 Correlation of Testing Techniques and Summary - Skip Hickey, USAF Aeronautical Systems Div.; and Jim Bowman, NASA Langley Research Center

1:30 Pilot Observations and Comments

F-15 Spin Tests - Lt. Col. C. P. Winters, Industrial College of the Armed Forces

F-15 RPRV and Simulation - Einar Enevoldson, NASA Dryden Flight Research Center

2:00 Break

2:15 Panel Discussion - Herman Rediess, NASA Dryden Flight Research Center, moderator; Carl Weyl, Northrop Corp.; Charles Anderson, General Dynamics/Fort Worth Div.; David Bowser, Air Force Flight Dynamics Laboratory; and J. T. Lawrence, Naval Air Systems Command

3:15 Closing Remarks

F-15 DESIGN PHILOSOPHY

Skip Hickey

USAF Aeronautical Systems Division

F-15 APPROACH TO STALL & SPIN PROGRAM

FX HIGH AOA DESIGN OBJECTIVES:

- DEPARTURE RESISTANT IN PITCH AND YAW - TO FULL AFT STICK AOA
- ACCEPTABLE ROLL RESPONSE - WITH FULL AFT STICK
- SPIN RECOVERABLE

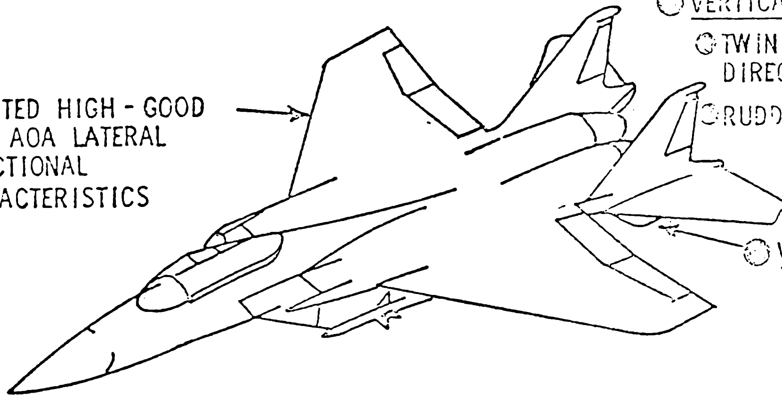
FX STUDY PHASE ZERO

- AERODYNAMIC DATA DISTRIBUTED - 5 FX CONTRACTORS FOR "SPIN RESISTANCE" STUDIES
- CONFIGURATION VARIABLES STUDIES - WHAT CHARACTERISTICS PROVIDE NECESSARY STABILITY

F-15 SOURCE SELECTION PHASE I

- WIND TUNNEL MODEL TESTS - PROPOSED CONFIGURATIONS TESTED (TO 90 DEGREES AOA) AT NASA/ARC
- DEPARTURE/SPIN RECOVERY ANALYSIS PERFORMED BY CONTRACTOR
- RECOVERY CHARACTERISTICS DEMONSTRATED - SPIN TUNNEL TESTS AT NASA/LRC

RESULT-MODEL 199B1 AT TIME OF SOURCE SELECTION



- WING
  - MOUNTED HIGH - GOOD HIGH AOA LATERAL DIRECTIONAL CHARACTERISTICS
- VERTICAL TAILS
  - TWIN TAILS - HIGH AOA DIRECTIONAL STABILITY
  - RUDDERS EFFECTIVE AT HIGH AOA
- VENTRALS
  - HIGH AOA DIRECTIONAL STABILITY
- HORIZONTAL TAIL
  - MOUNTED BELOW WING - PRECLUDES "PITCH-UP AND NOSE RISE"
  - DIFFERENTIALLY DEFLECTED WITH AILERONS-HIGH ROLL RESPONSE
  - PROVIDES SPIN RECOVERY
- CONTROL AUGMENTATION SYSTEM
  - AILERON RUDDER INTERCONNECT FOR HIGH AOA
  - CAS SHUTS OFF IN SPIN FOR SPIN RECOVERY

SYSTEM DEVELOPMENT PHASE II - PRIOR TO CDR

- WIND TUNNEL DATA (TO 90° AOA) - ANALYSIS OF STALL/ SPIN CHARACTERISTICS AT NASA/ARC AND AEDC 16T
- PILOTED SIMULATION USED TO DEVELOP MCS AND CAS
- SPIN TUNNEL TESTS
  - IDENTIFIED SPIN MODES
  - IDENTIFIED/VERIFIED SATISFACTORY RECOVERY TECHNIQUES
  - USED REVISED EMPENNAGE

SYSTEM DEVELOPMENT PHASE II - AFTER CDR - BUT PRIOR TO FIRST FLIGHT

- 13% RADIO CONTROLLED DROP MODEL - NASA/LRC
  - PROVIDE FLIGHT TEST DATA FOR CORRELATION - PRIMARILY TO INCREASE CONFIDENCE IN FULL SCALE PREDICTIONS.
  - OBTAIN FLIGHT TEST DATA ON DEPARTURE.
  - VERIFY SPIN TUNNEL RESULTS.
- 3/8 SCALE REMOTELY PILOTED RESEARCH VEHICLE - NASA/FRC
  - PROVIDED LARGE SCALE VERIFICATION OF DEPARTURE AND SPIN.
  - PROVIDED MORE COMPLETE REPRESENTATION OF FLIGHT CONTROL SYSTEM.
  - VERIFIED AERODYNAMIC CONTROL POWER SUFFICIENT TO RECOVER FROM FULLY DEVELOPED MODES.

FLIGHT TEST STALL/SPIN PROGRAM OBJECTIVES

- FULL SCALE VERIFICATION OF HIGH ANGLE OF ATTACK FLYING QUALITIES AND SPIN RECOVERY CHARACTERISTICS OF THE TOTAL F-15 SYSTEM.

    AERODYNAMIC CONTROL

    HYDRAULIC POWER

    PILOT ORIENTATION

- TO CLEAR OPERATIONAL AIRCRAFT FOR MAXIMUM MANEUVERING.
- TO DEVELOP CONFIDENCE MANEUVERS TO TRAIN OPERATIONAL PILOTS FOR MAXIMUM MANEUVERING WITHOUT FEAR OF LOSS OF CONTROL.

FLIGHT TEST SPIN PROGRAM

- PILOTS
  - TWO CONTRACTOR
  - TWO AIR FORCE
- 189 FLIGHTS
- 1164 HIGH AOA ENTRY MANEUVERS
- 115 INTENTIONAL SPINS

F-15

SPIN TESTING WORKSHOP

DESIGN AND PREDICTIONS FOR F-15

MAY 20,1976

J. F. MELLO

MCDONNELL DOUGLAS CORPORATION

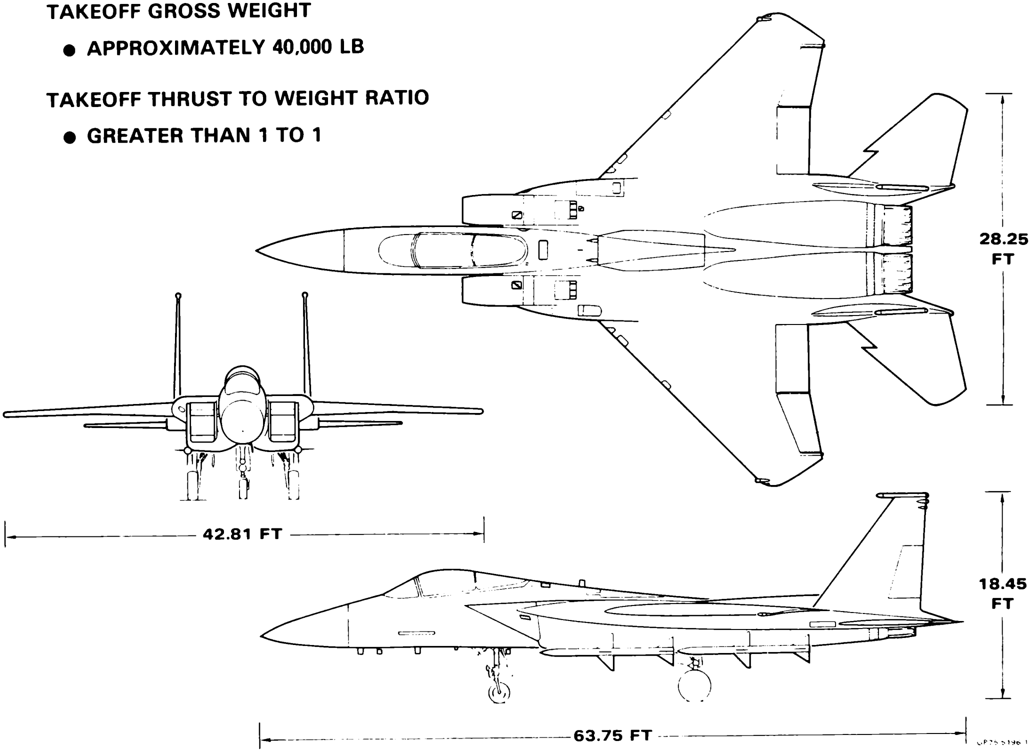
F-15A GENERAL ARRANGEMENT

TAKEOFF GROSS WEIGHT

- APPROXIMATELY 40,000 LB

TAKEOFF THRUST TO WEIGHT RATIO

- GREATER THAN 1 TO 1



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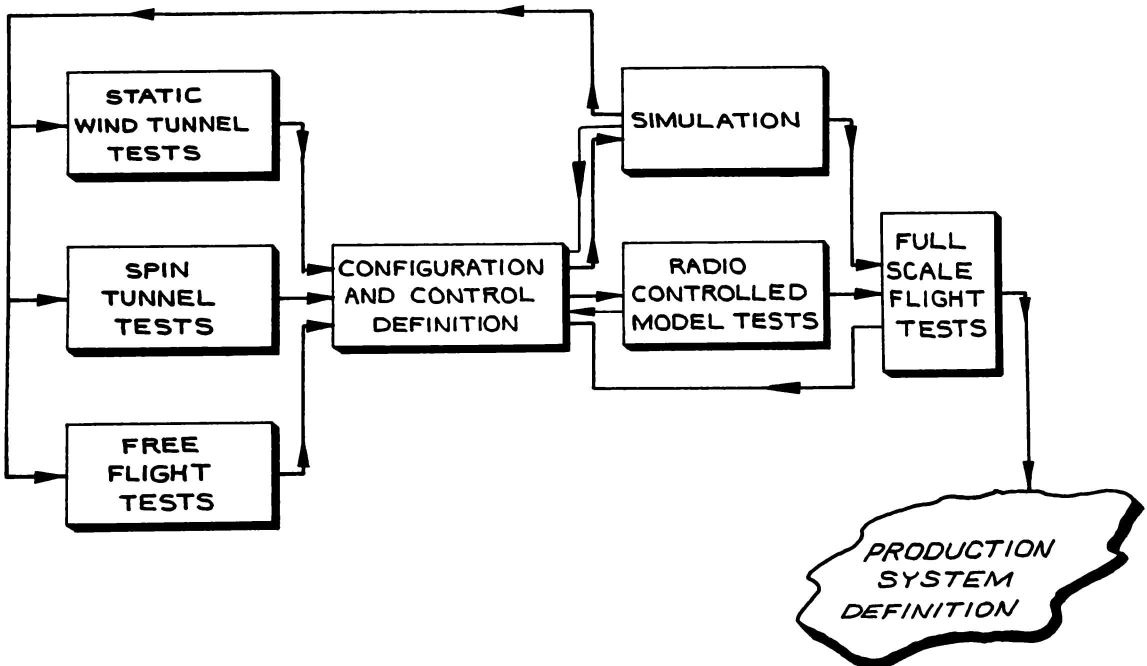
CONFIGURATION DEVELOPMENT



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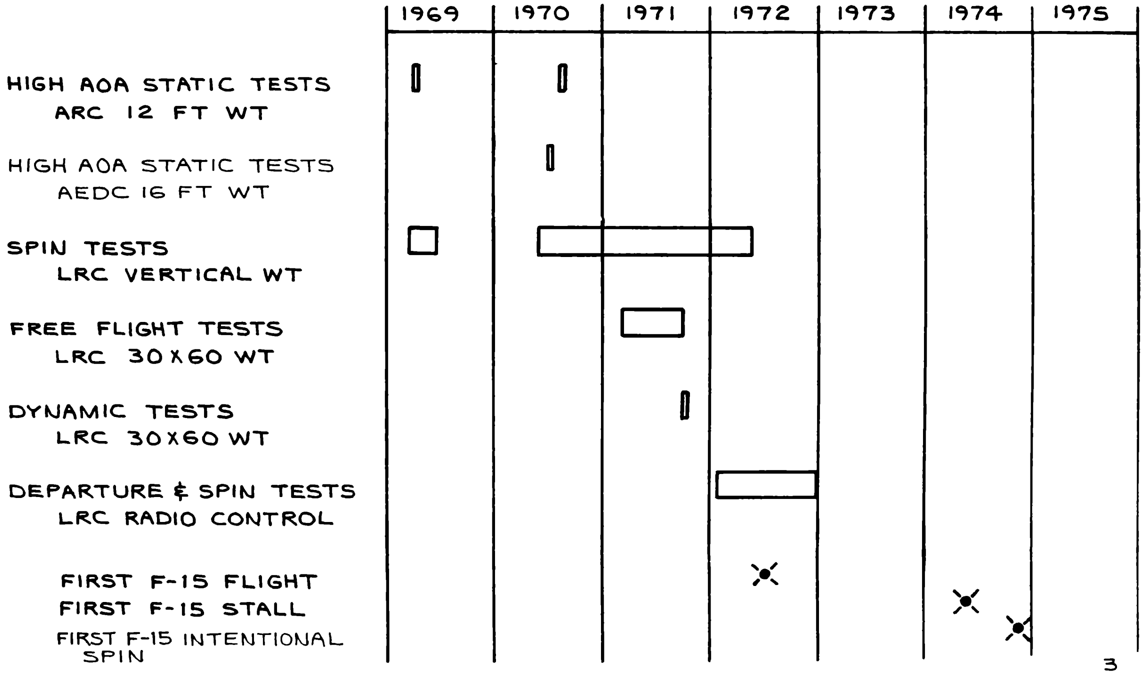
MODEL F-15

DEPARTURE AND SPIN RELATED MODEL TESTS



F-15

DESIGN CRITERIA FOR DEPARTURE AND SPIN RESISTANCE AND RECOVERY

- LONGITUDINAL AXIS REQUIREMENT

  STABLE BREAK AT STALL

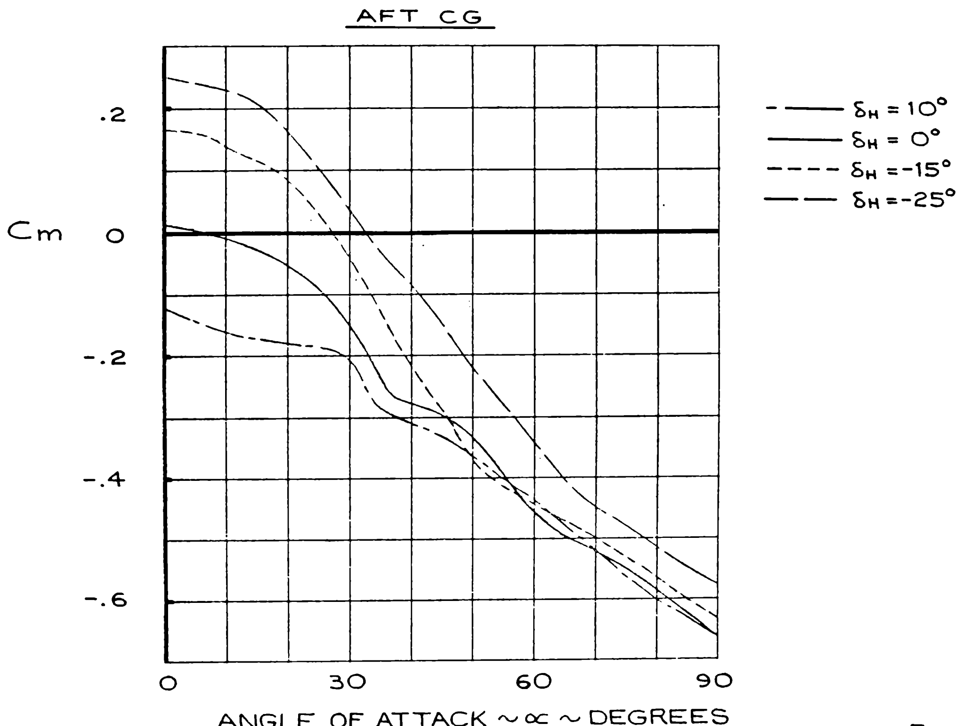
- LATERAL-DIRECTIONAL AXES REQUIREMENT

  POSITIVE DIRECTIONAL STABILITY IN STABILITY AXES SYSTEM FOR $\alpha \leq TRIM \alpha_{MAX}$

- CONTROL

  CONTROL FOR RAPID SPIN RECOVERY
  CONTROL AUGMENTATION SYSTEM AUTOMATIC SHUT OFF AT DEPARTURE ($r \approx 35$ DEG/SEC)

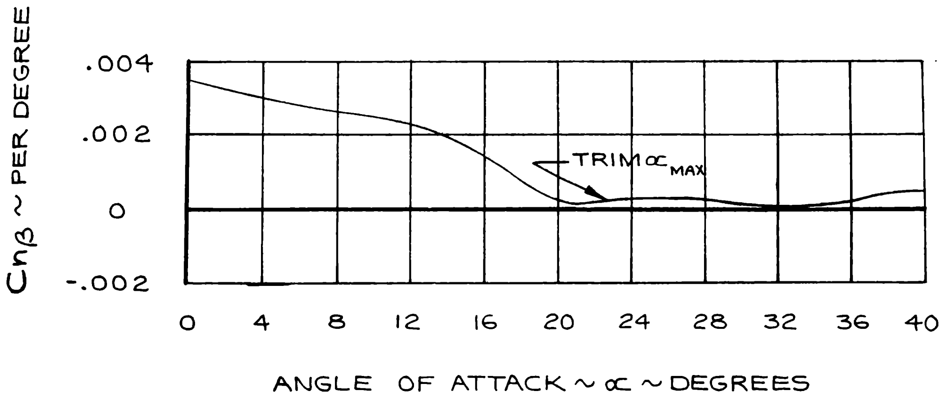
STATIC PITCHING MOMENT COEFFICIENT



DIRECTIONAL STABILITY

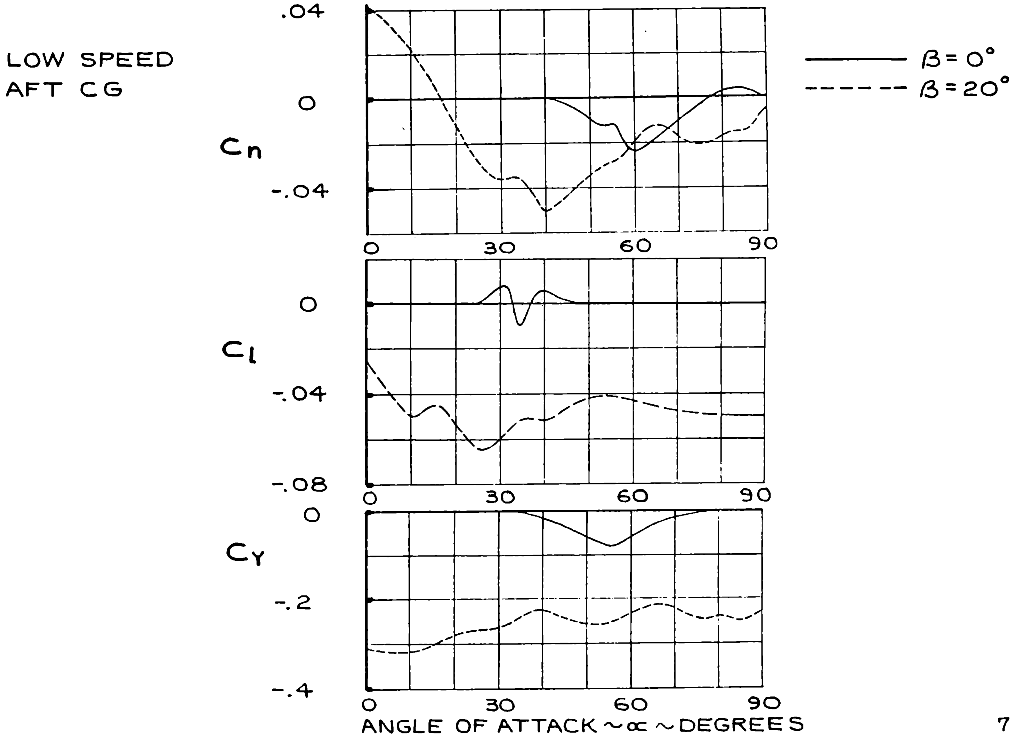
$M = 0.90$

STABILITY AXES SYSTEM



LATERAL DIRECTIONAL STABILITY

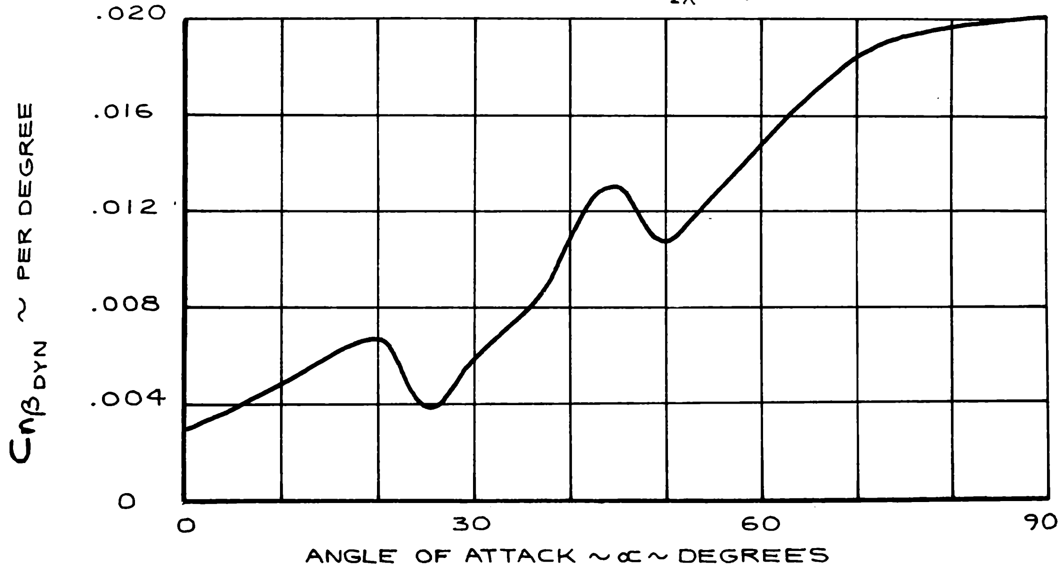
BODY AXES



DYNAMIC STABILITY

LOW SPEED

$$C_{n_{\beta_{DYN}}} = C_{n_\beta} \cos\alpha - \frac{I_z}{I_x} C_{l_\beta} \sin\alpha$$

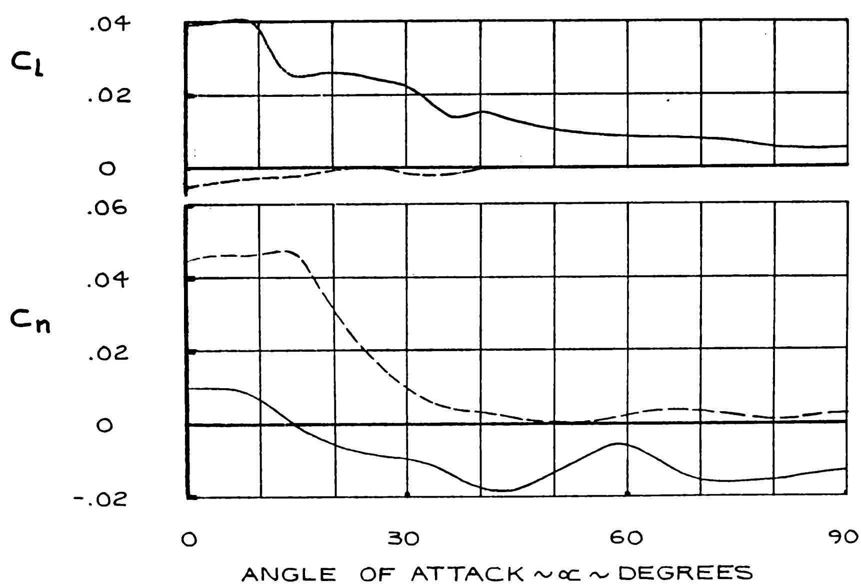


LATERAL-DIRECTIONAL CONTROL POWER

LOW SPEED

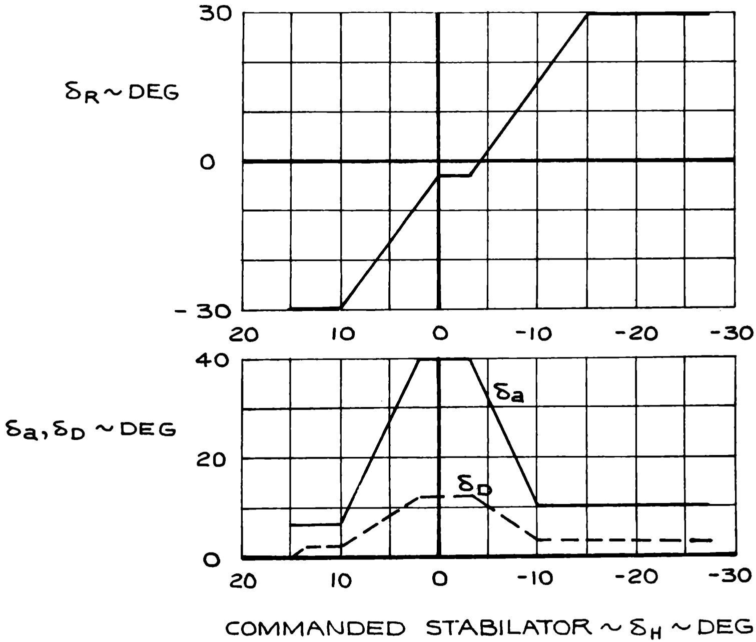
$\delta_a = 40°$
$\delta_D = 12°$
$\delta_R = -30°$

$\delta_H = 0°$



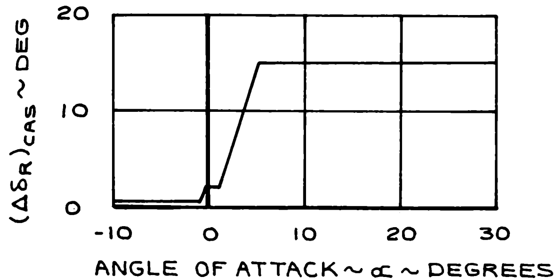
LATERAL CONTROL AUTHORITY

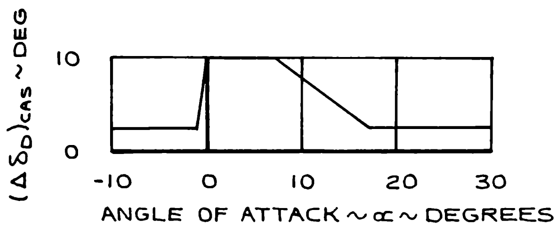
MECHANICAL CONTROL SYSTEM (MCS)



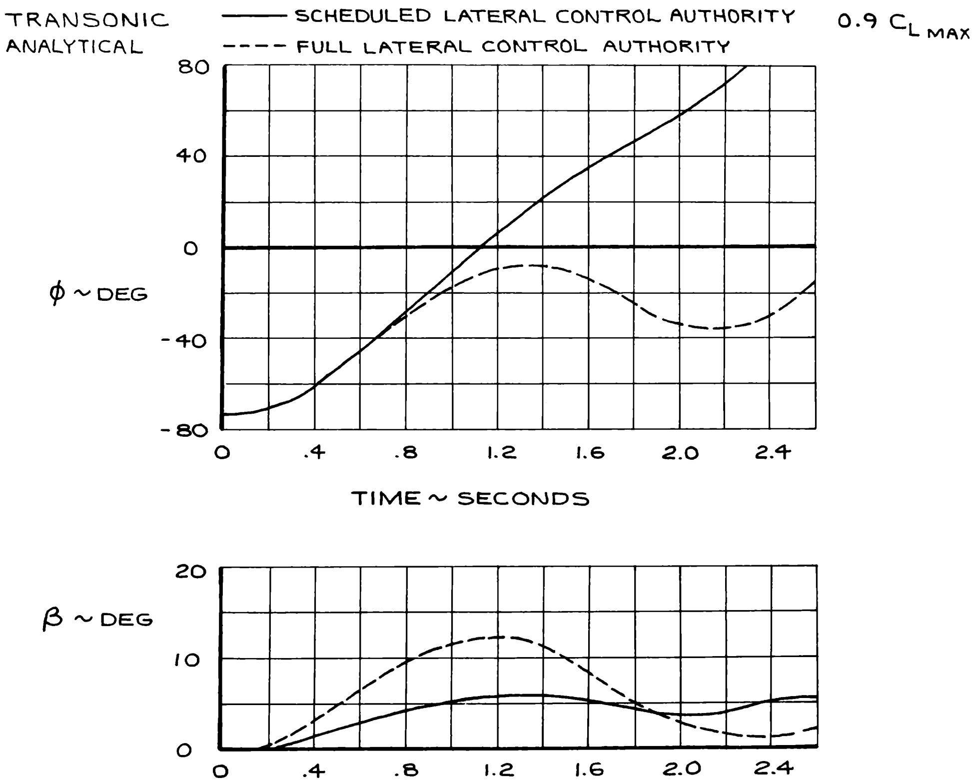
LATERAL CONTROL AUTHORITY

CONTROL AUGMENTATION SYSTEM (CAS)

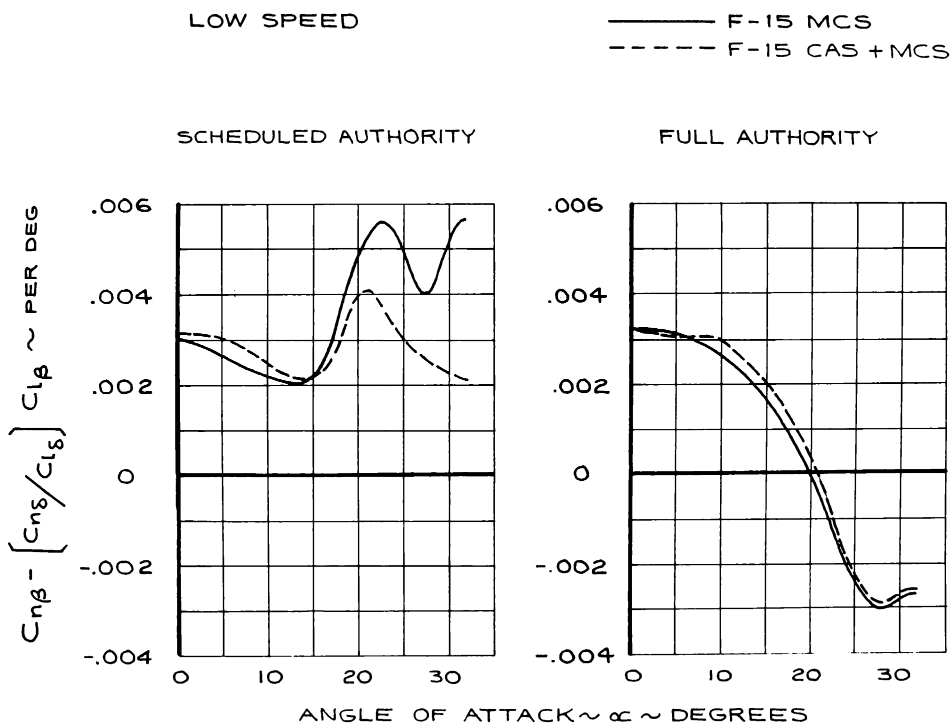




EFFECT OF MCS FEATURES ON ROLL RESPONSE

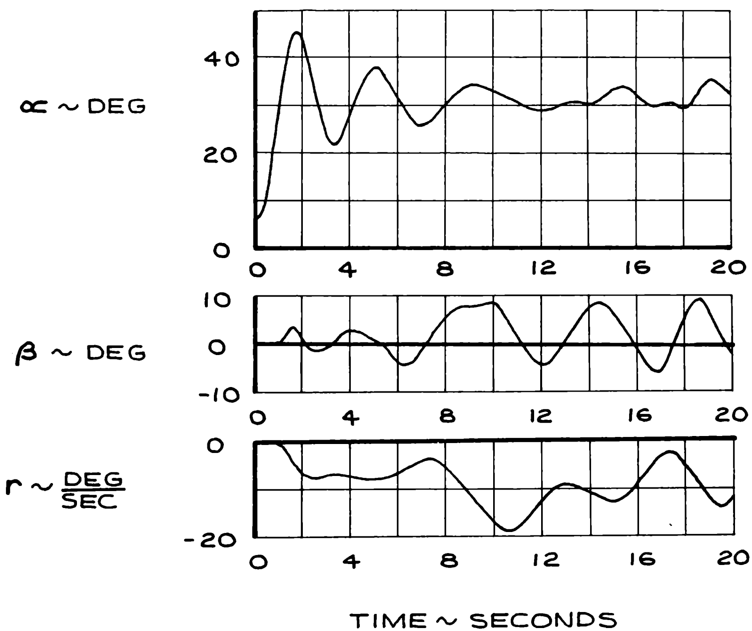


LATERAL CONTROLLABILITY



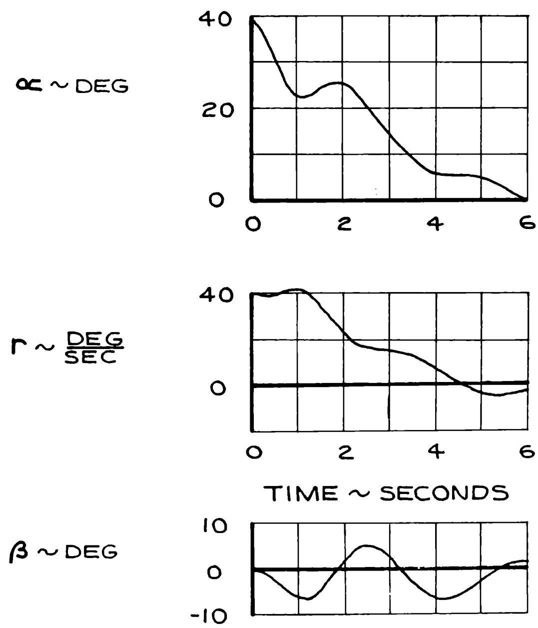
DEPARTURE RESISTANCE
ABRUPT PULL-UP WITH NEUTRAL CONTROLS

AFT CG
ANALYTICAL



RECOVERY FROM A DEPARTURE WITH NEUTRAL CONTROLS

ANALYTICAL

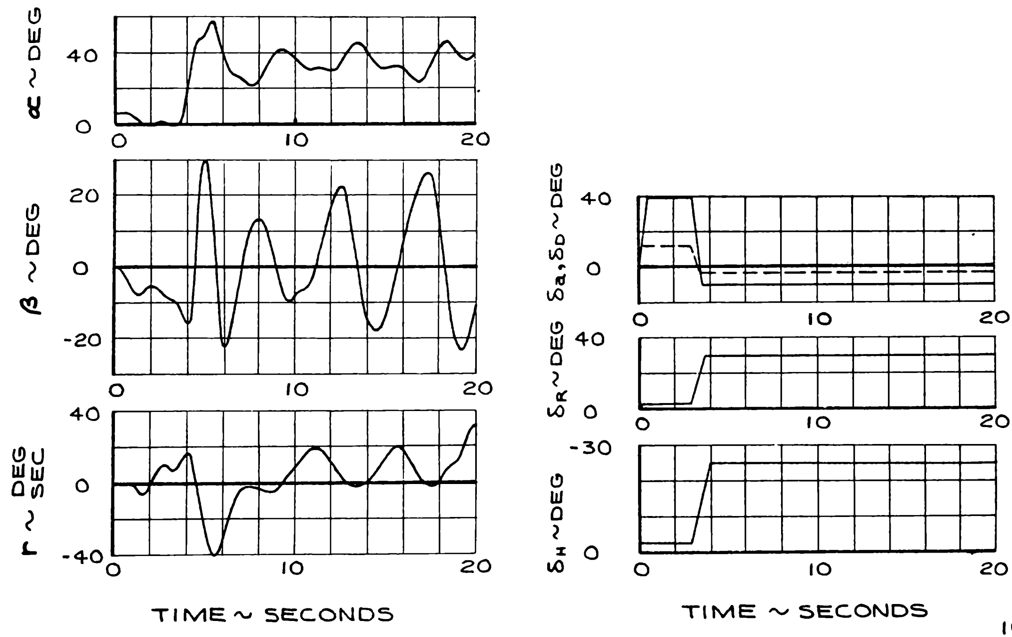


SPIN ENTRY ATTEMPT

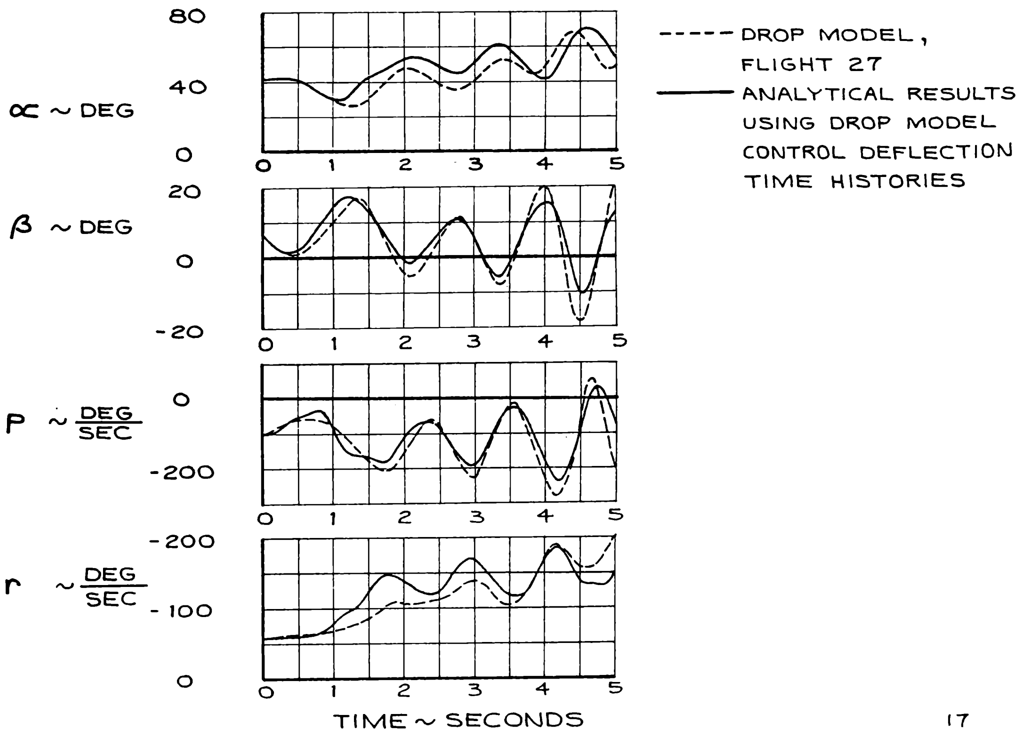
ABRUPT PULL-UP IN A 1g ROLL

AFT CG

ANALYTICAL

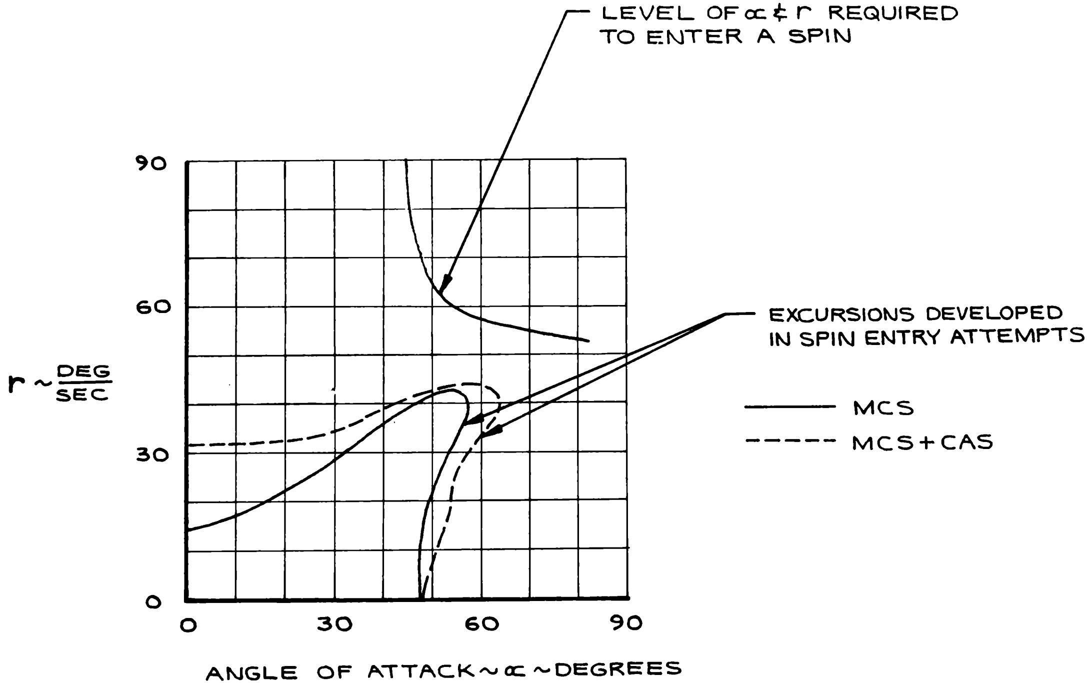


SIMULATION OF 13% SCALE DROP MODEL SPIN ENTRY ATTEMPT



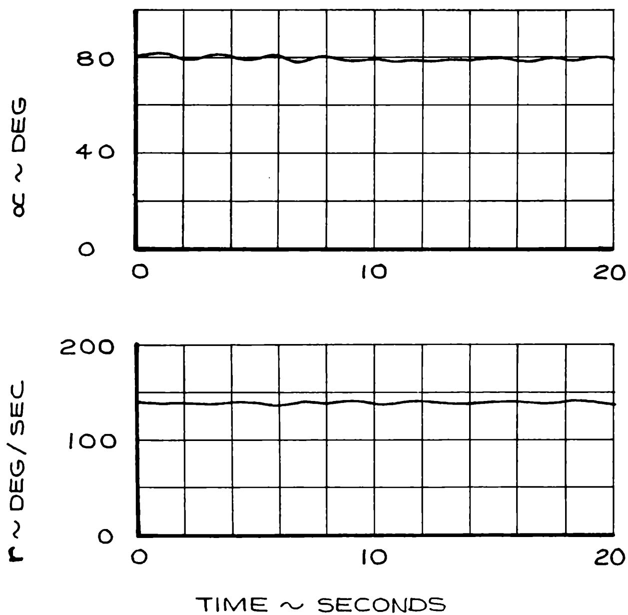
SPIN RESISTANCE

ANALYTICAL

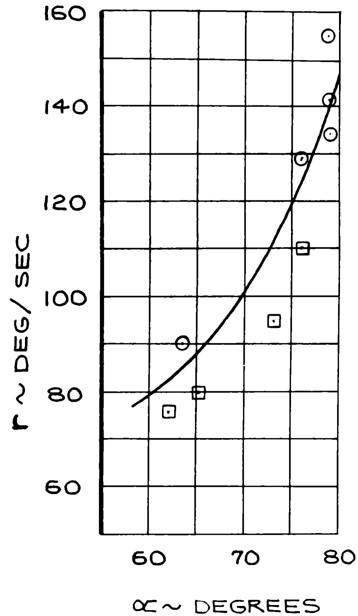


DEVELOPED SPIN CHARACTERISTICS

ANALYTICAL SPIN TRAJECTORY
MAX PRO-SPIN CONTROLS



STEADY SPIN RATE
— ANALYTICAL ESTIMATE
○ SPIN TUNNEL RESULTS
□ 13% SCALE DROP MODEL RESULTS



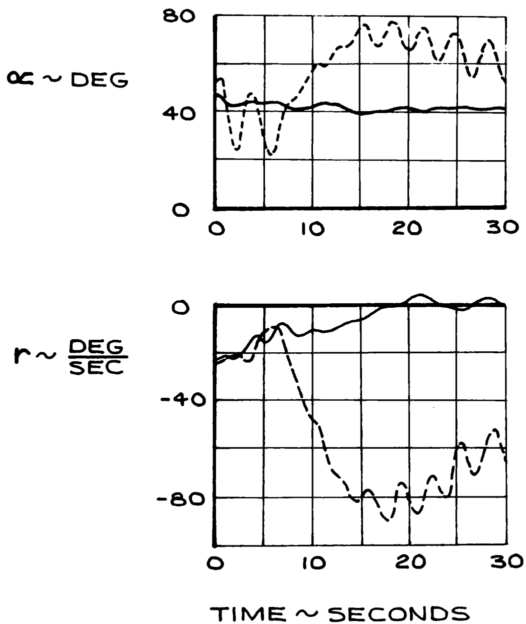
EFFECT OF MCS ON SPIN RESISTANCE

13% SCALE HELICOPTER DROP MODEL RESULTS

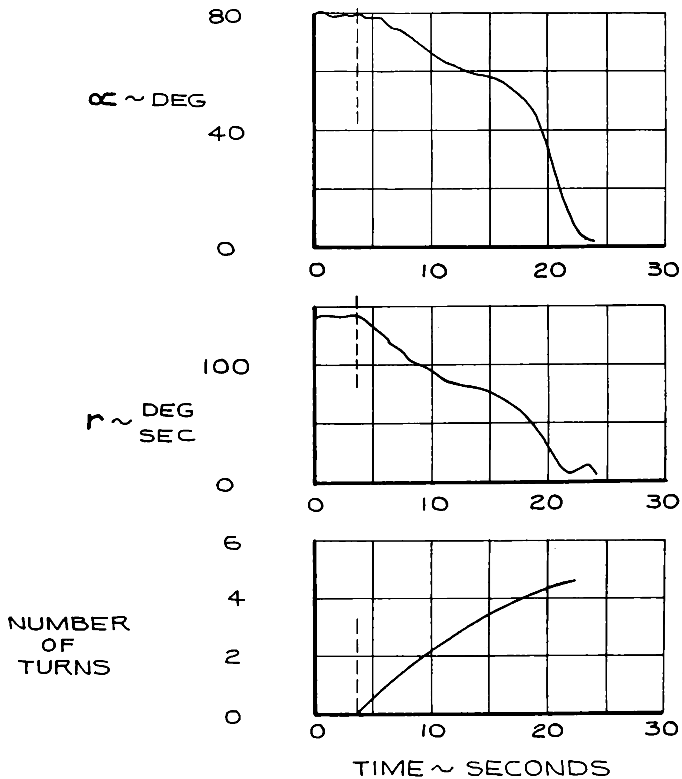
FULL PRO-SPIN CONTROLS AT AFT STICK

——— WITH SCHEDULED LATERAL CONTROL AUTHORITIES

– – – – – WITH FULL AUTHORITY



ANALYTICAL SPIN RECOVERY



SUMMARY

MODEL TEST / ANALYSES PREDICTED THAT THE F-15 WOULD BE —

- DEPARTURE RESISTANT
  - NO "PITCH-UP" AND NO "NOSE SLICE"
- DEPARTURE RECOVERABLE
  - QUICKLY RECOVER WHEN CONTROLS ARE NEUTRALIZED
- SPIN RESISTANT
  - SPINS MUST BE FORCED BY DEFTLY MANIPULATING CONTROLS
- SPIN RECOVERABLE
  - OSCILLATORY SPIN – NEUTRAL CONTROLS
  - SMOOTH SPIN – PITCH NEUTRAL / LATERAL WITH SPIN

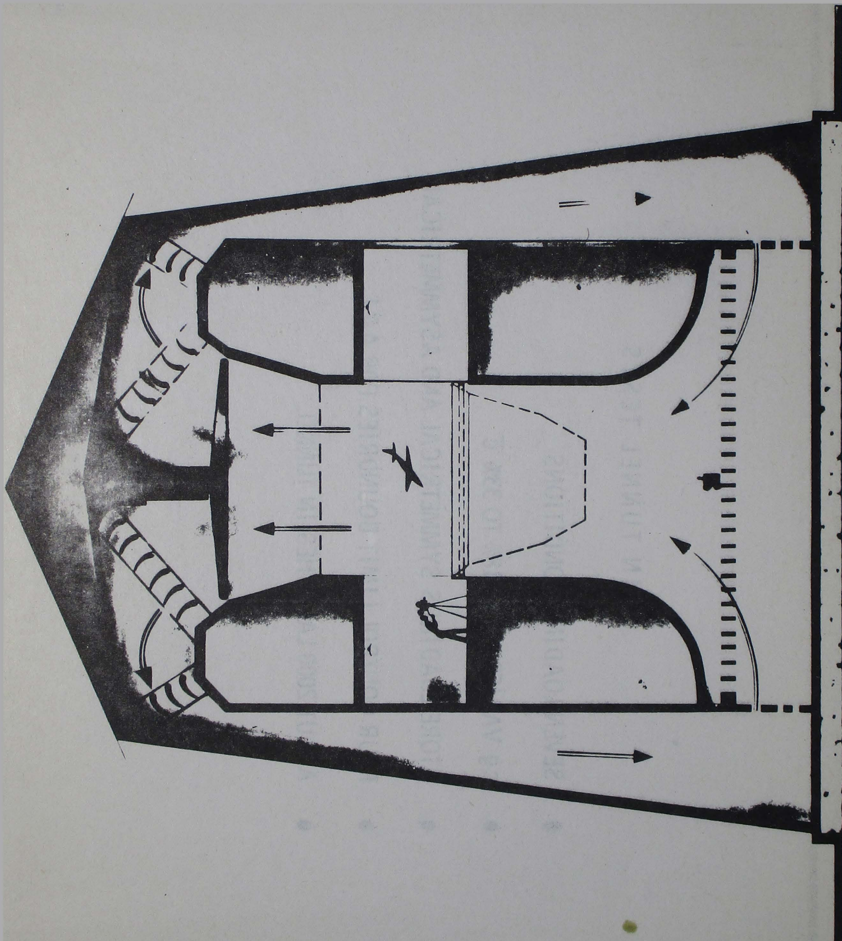
SPIN TUNNEL AND HELICOPTER DROP MODEL TESTS

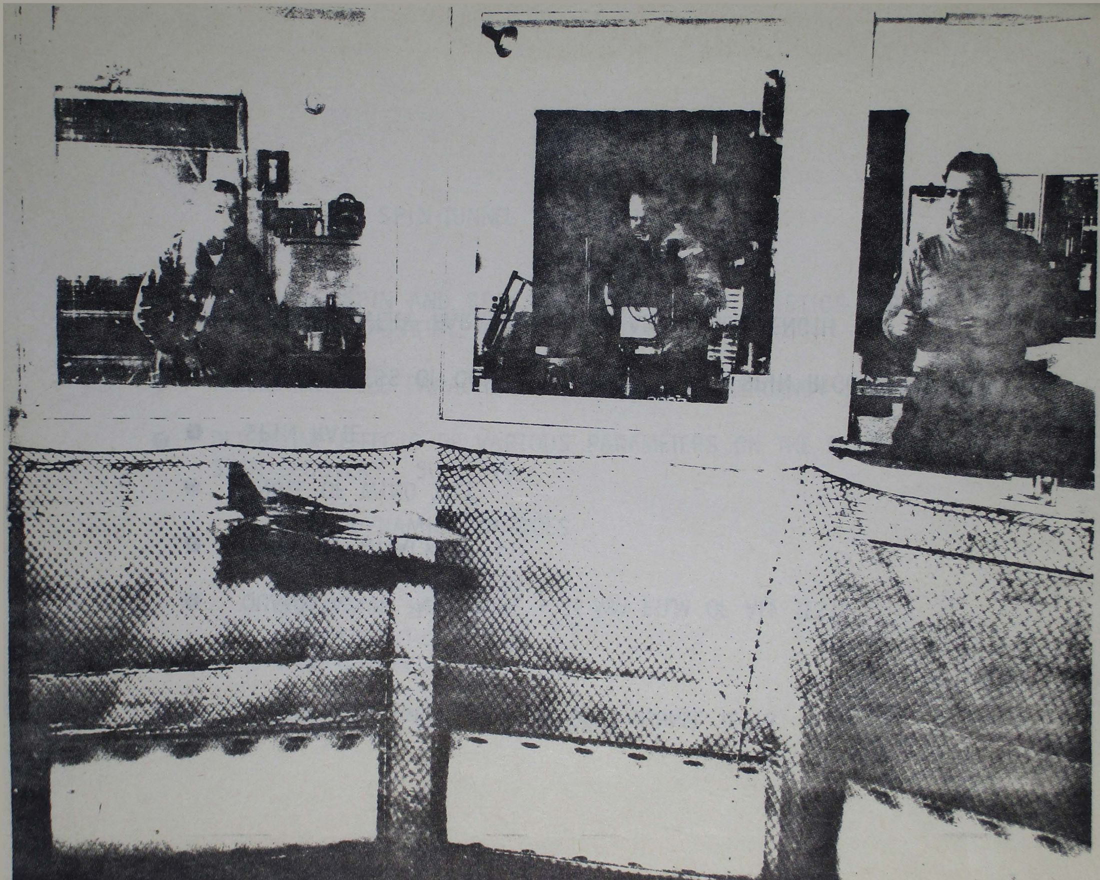
Jim Bowman

NASA Langley Research Center

SPIN TUNNEL TESTS

- SEVEN LOADING CONDITIONS
- cg VARIED FROM 18% TO 33% $\bar{c}$
- STORE LOADINGS SYMMETRICAL AND ASYMMETRICAL
- FOUR CONTROL LIMIT BOUNDRIES FOR ARI
- ABOUT 2000 LAUNCHES IN TUNNEL



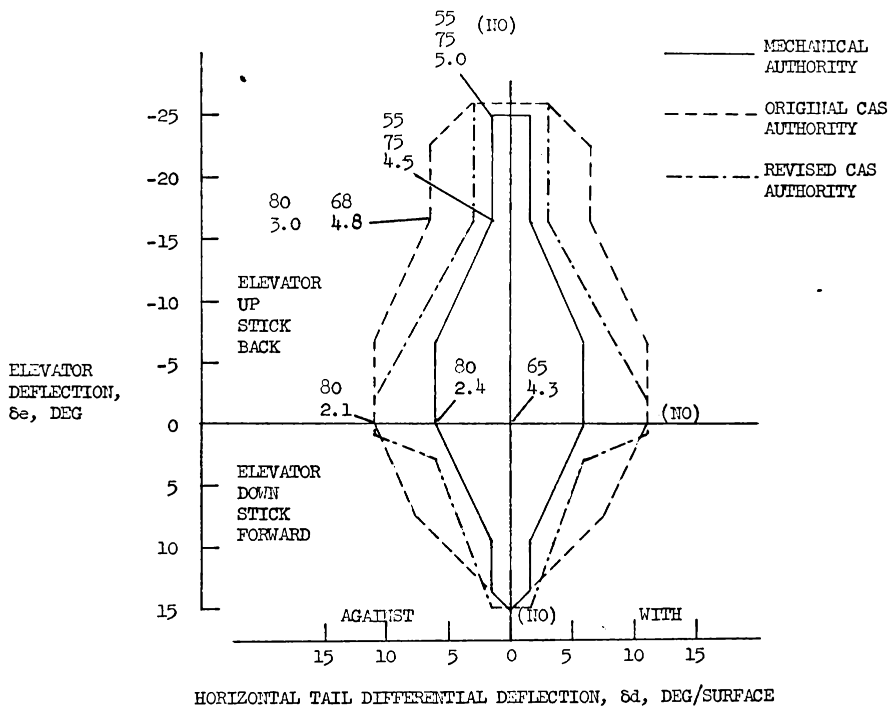


DATA OBTAINED FROM THE SPIN-TUNNEL TESTS

- QUANTITATIVE IN NATURE – 16-MM FILM OF ALL TESTS
- ANGLE OF ATTACK
- ANGLE OF WING TILT
- SPIN RATE
- EFFECTIVENESS OF CONTROLS ON SPIN AND SPIN RECOVERY
- SPIN-RECOVERY PARACHUTE SIZE AND RISER LENGTH

SPIN-TUNNEL TEST TECHNIQUE

- DETERMINE SPIN AND SPIN RECOVERY CHARACTERISTICS FOR ALL SPIN MODES POSSIBLE ON THE AIRPLANE
- DETERMINE SIZE PARACHUTE REQUIRED FOR EMERGENCY SPIN RECOVERY
- DETERMINE EFFECTS OF VARIOUS PARAMETERS ON THE SPIN AND SPIN RECOVERY, SUCH AS
  - AERODYNAMIC CONTROLS
  - CENTER OF GRAVITY
  - MASS DISTRIBUTION
  - EXTERNAL STORES
  - LEADING-EDGE SLATS
  - TRAILING-EDGE FLAPS
  - SPEED BRAKES
  - ENGINE GYROSCOPIC MOMENTS

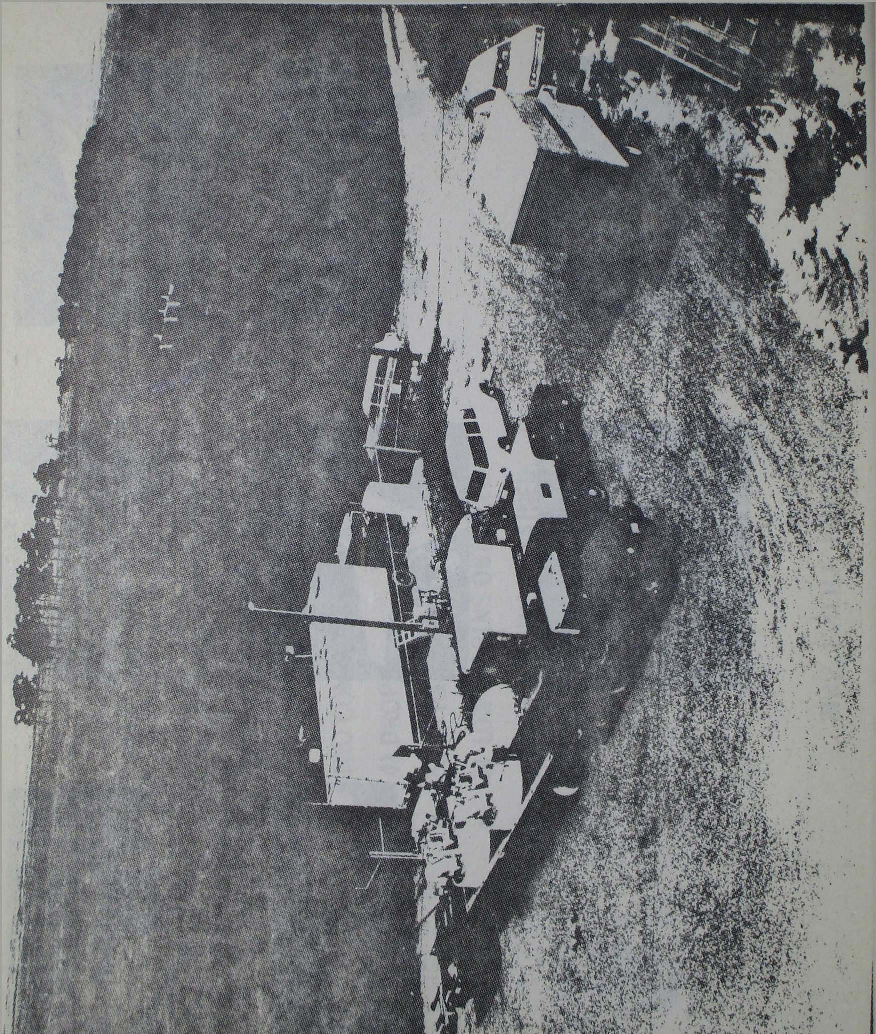

ELEVATOR DEFLECTION, δe, DEG
-25
-20
-15
-10
-5
0
5
10
15
ELEVATOR UP STICK BACK
ELEVATOR DOWN STICK FORWARD
55 75 5.0
(NO)
55 75 4.5
80 3.0
68 4.8
80 2.1
80 2.4
65 4.3
(NO)
(NO)
AGAINST
WITH
15 10 5 0 5 10 15
HORIZONTAL TAIL DIFFERENTIAL DEFLECTION, δd, DEG/SURFACE
MECHANICAL AUTHORITY
ORIGINAL CAS AUTHORITY
REVISED CAS AUTHORITY

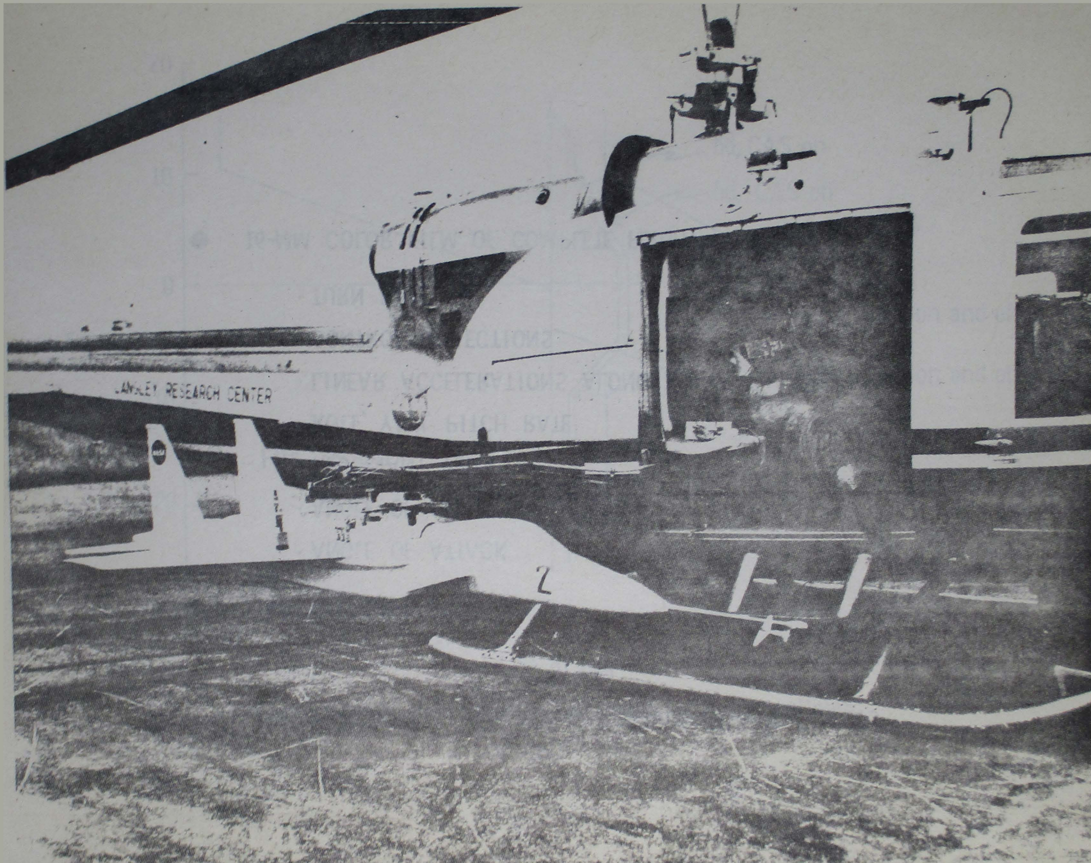
SPIN TUNNEL RESULTS

SPIN MODES	α, deg	Φ, deg	Ω, sec/turn	RECOVERY
ERECT				
Oscillatory	55-75	± 25	5	1 to 2 turns δa δr
Smooth H High - α	80	± 5	2 to 3	4 to 5 turns δa δr
INVERTED				
Oscillatory	50 - 60	± 10	4.5	1 to 2 δ's $\rightarrow 0$
Smooth	40		6.5	1 δ's $\rightarrow 0$
Very Steep	< 40		5	$\frac{1}{4}$ $\delta' \rightarrow 0$

- Model results indicated that the smooth high-α spin to be predominate
- Oscillatory spin obtained stick back positions as well as "no spins"
- Parachute diameter = 34 feet ($C_D = .5$)

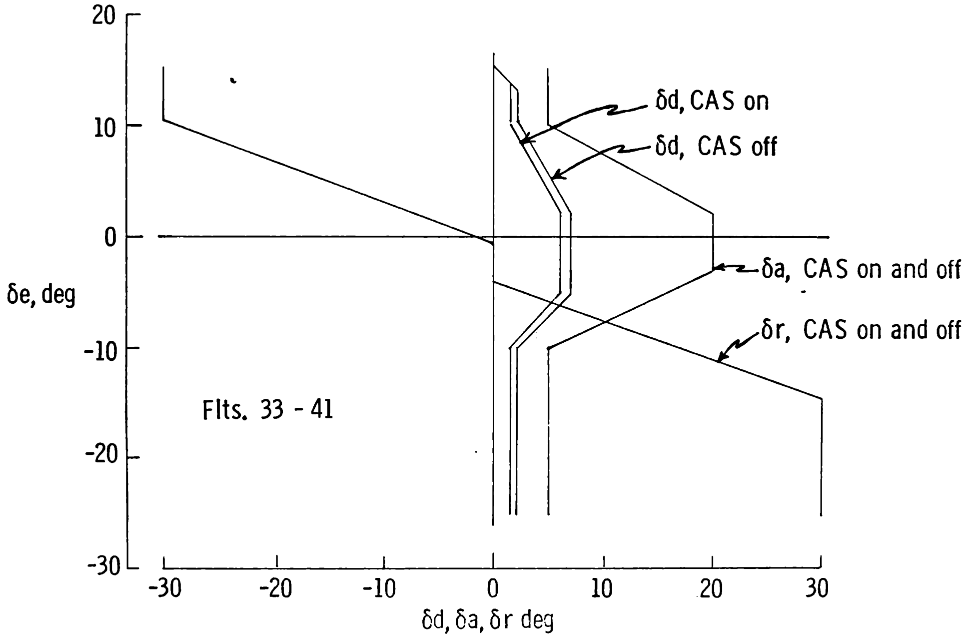
  d, riser plus suspension lines = 100 feet



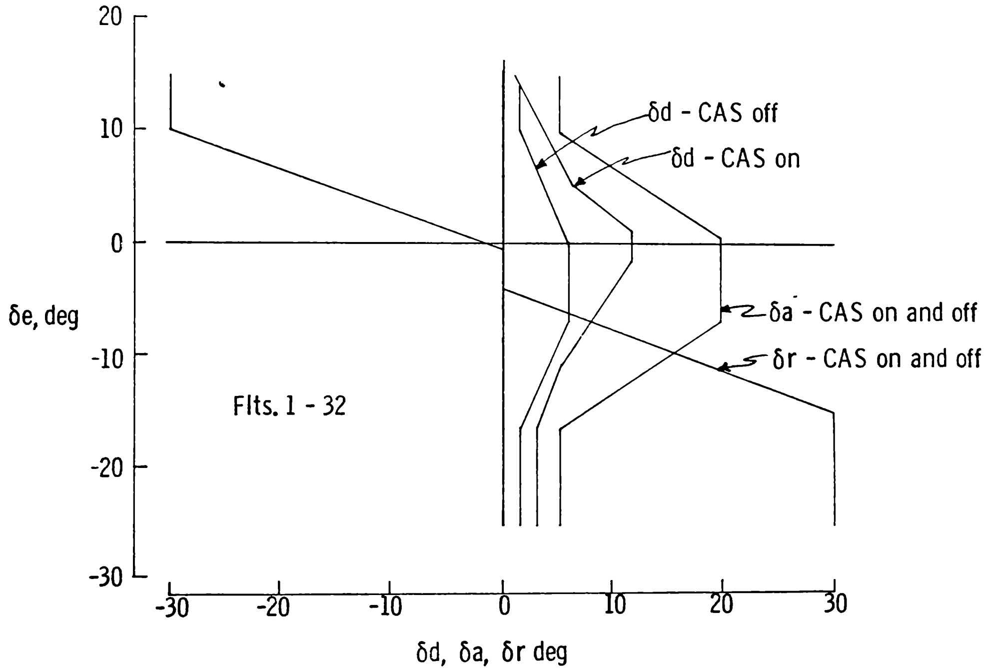

LANGLEY RESEARCH CENTER

DATA OBTAINED FROM RADIO-CONTROLLED MODEL TESTS

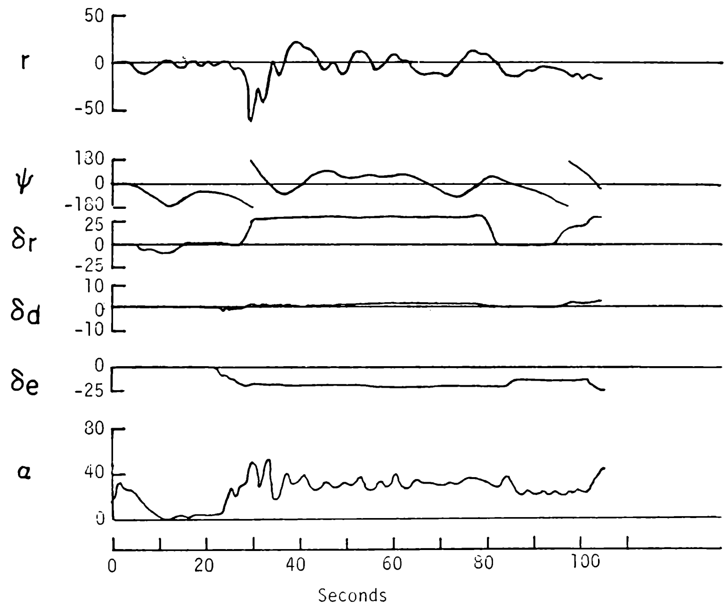
- TIME HISTORY OF FLIGHT
  - ANGLE OF ATTACK
  - ANGLE OF SIDESLIP
  - RESULTANT VELOCITY
  - ROLL, YAW, PITCH RATE
  - LINEAR ACCELERATIONS ALONG X-, Y-, Z-AXES
  - CONTROL DEFLECTIONS
  - TURN RATE
- 16-MM COLOR FILM OF COMPLETE FLIGHT



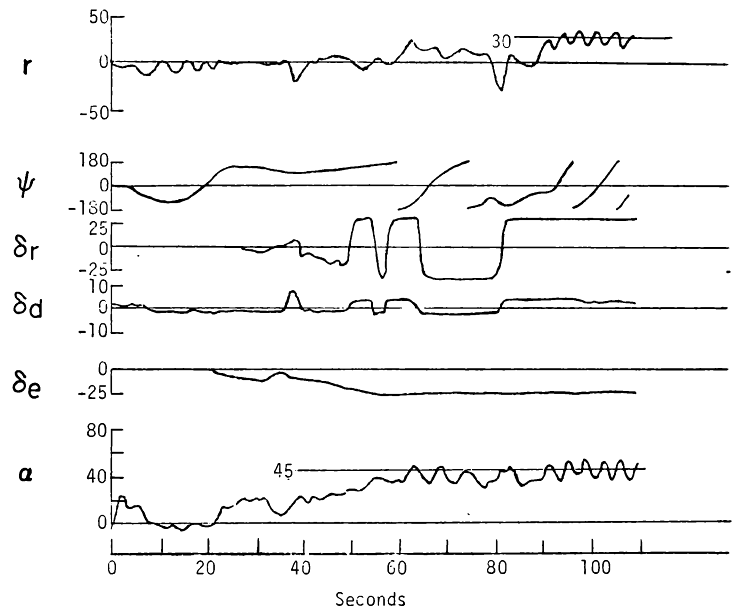
Maximum lateral-directional control deflections available
Configuration B



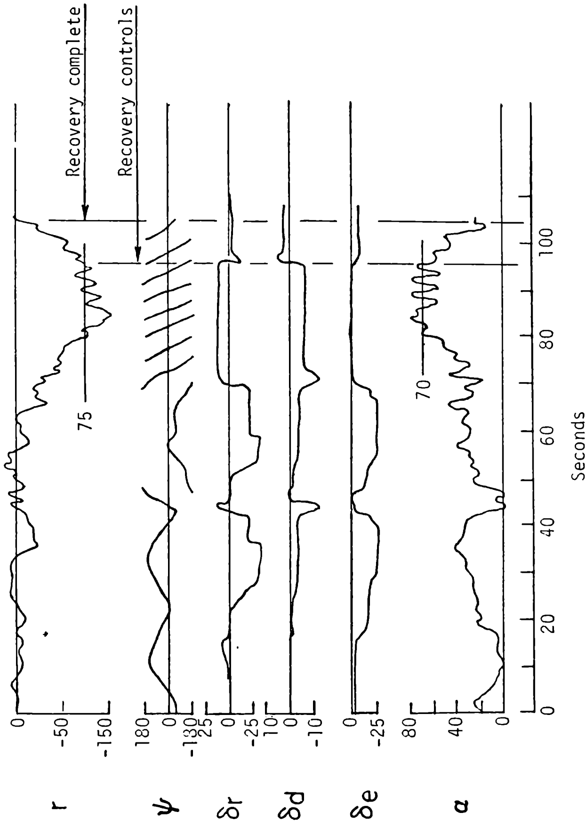
Maximum lateral-directional control deflections available
Configuration A



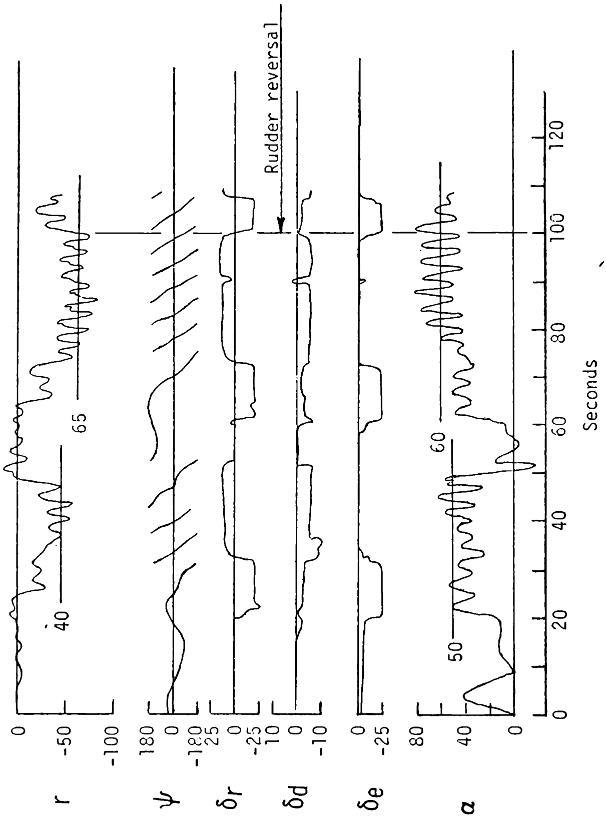
DEPARTURE, NO SPIN



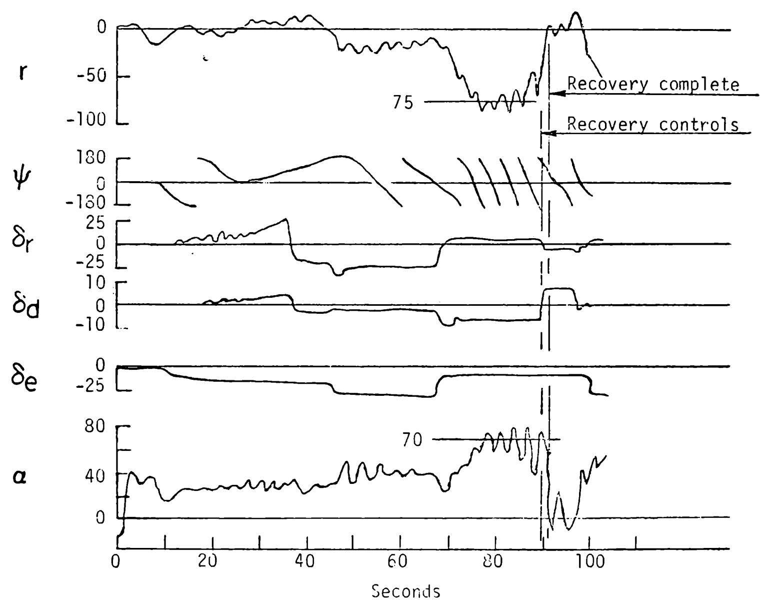
STEEP OSCILLATORY SPIN/STICK BACK



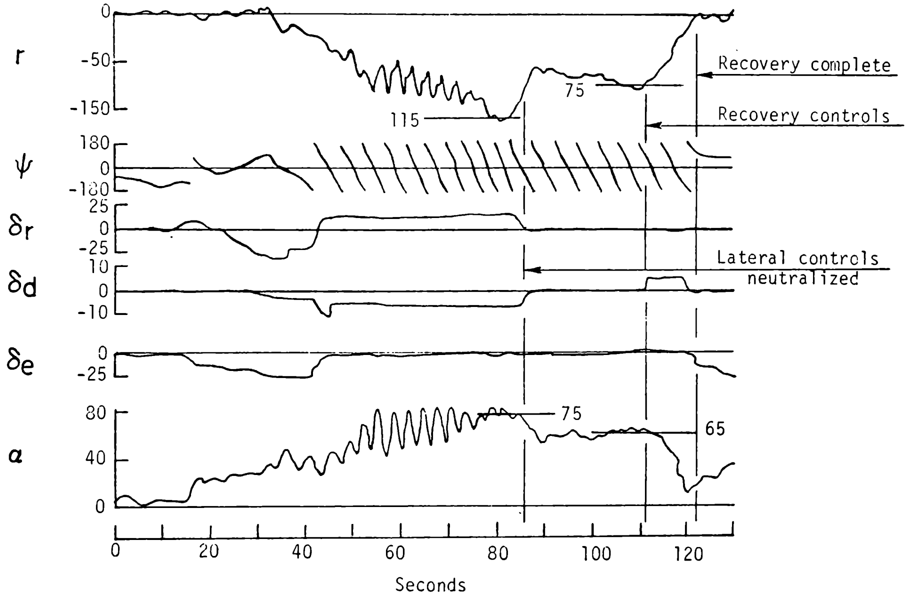
OSCILLATORY SPIN



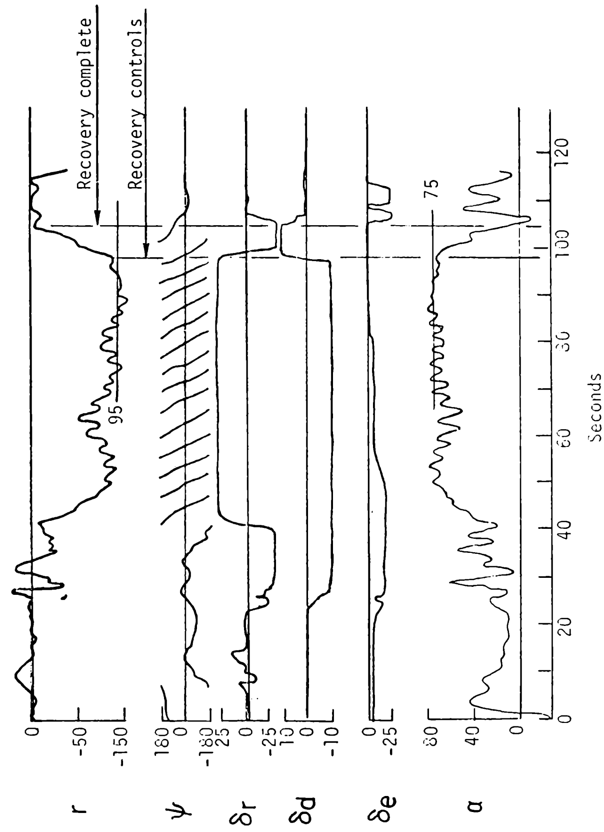
OSCILLATORY SPIN



HIGH-α OSCILLATORY SPIN



HIGH-α SPIN AND SMOOTH SPIN



HIGH-α SPIN - NO ARI AND NO AILERON WASHOUT

RADIO CONTROL MODEL RESULTS

MOTION	α, deg	Ω, sec/turn	RECOVERY
Erect Spins * Oscillatory low α	40 - 75	5 - 12	δa with, δr against $\frac{1}{2}$ to $2\frac{1}{4}$
Smooth high α	60 - 80	3 - 4	1 to $3\frac{1}{2}$
Erect Post Stall Gyrations	30	N. A.	N. A.

* 5 low α oscillatory spins self recovered while holding pro-spin controls

$1\frac{3}{4}$, 3, $2\frac{1}{2}$, $2\frac{1}{2}$, 4 turns completed before recovery occured

SPIN TUNNEL RESULTS

RECOMMENDED RECOVERY TECHNIQUE FOR ALL OUT OF CONTROL MOTIONS

1. Neutralize all controls.
   If recovery has not stopped within 2 turns -

2. Move rudder to full against
   ailerons to full with
   elevators to neutral

For inverted spins, neutralize all controls

REMOTELY PILOTED 3/8-SCALE MODEL TEST AND RESEARCH

Ken Iliff

NASA Dryden Flight Research Center

REMOTELY PILOTED 3/8-SCALE MODEL TESTS AND RESEARCH

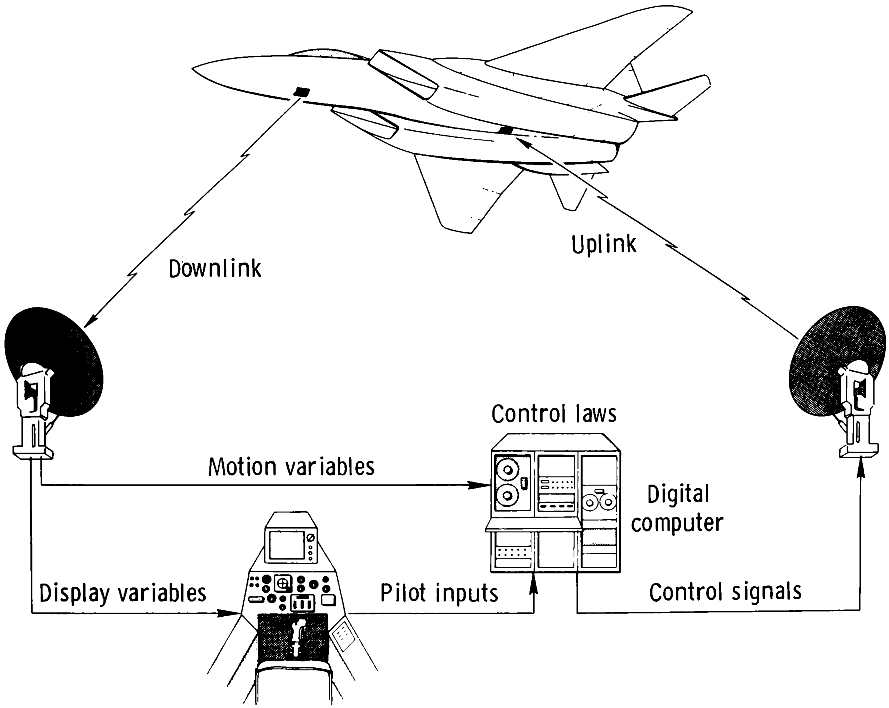
Results that apply primarily to F-15 airplane

Results that apply to general spin research

RESULTS THAT APPLY PRIMARILY TO F-15 AIRPLANE

- Remotely piloted research vehicle concept
- Simulation
- High angle of attack results
- Vehicle characteristics that simulate control system of full-scale F-15 airplane
  - Spin entry
  - Spin
  - Spin recovery

REMOTELY PILOTED RESEARCH VEHICLE TECHNIQUE



ADVANTAGES OF REMOTELY PILOTED RESEARCH VEHICLE TECHNIQUE

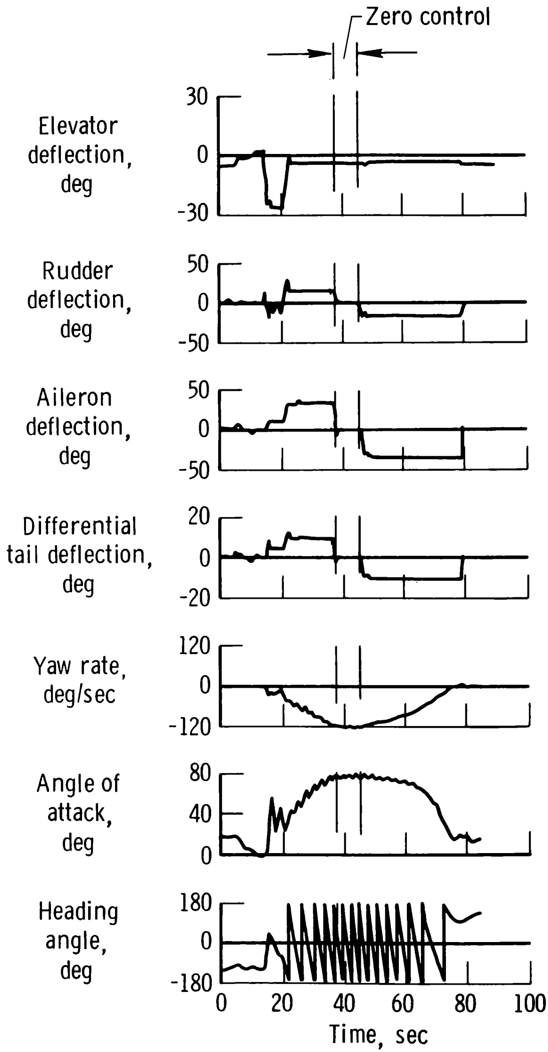
- "Simple" construction
- High risk testing possible
    - Aft center of gravity, 38-percent mean aerodynamic chord
    - Sustained spins at high rates
- Less ground testing required because only vehicle risked
- Rapid envelope expansion
    - 4° to 23° on first flight
- Large stabilized angle of attack range
- Relatively simple to modify control system
    - Large ground-based computer
        - Complex control laws
    - Rapid major changes
        - Three days to make and verify major control system changes
- Pilot-in-the-loop assessments possible
- Rapid program development
    - Four control configurations evaluated in 5-minute flight
    - Eleven spins obtained before full-scale spin tests

USE OF VEHICLE SIMULATION

- Represented nonlinear force and moment characteristics throughout entire flight envelope
- Was updated with 3/8-scale model flight data before initial spin attempts
- Aided flight planning
  - More useful data obtained from short flights
- Predicted spin resistance
- Used to develop two spin entry techniques that were successful in flight

TYPICAL MODEL SIMULATOR SPIN

All Units Referenced to Full Scale

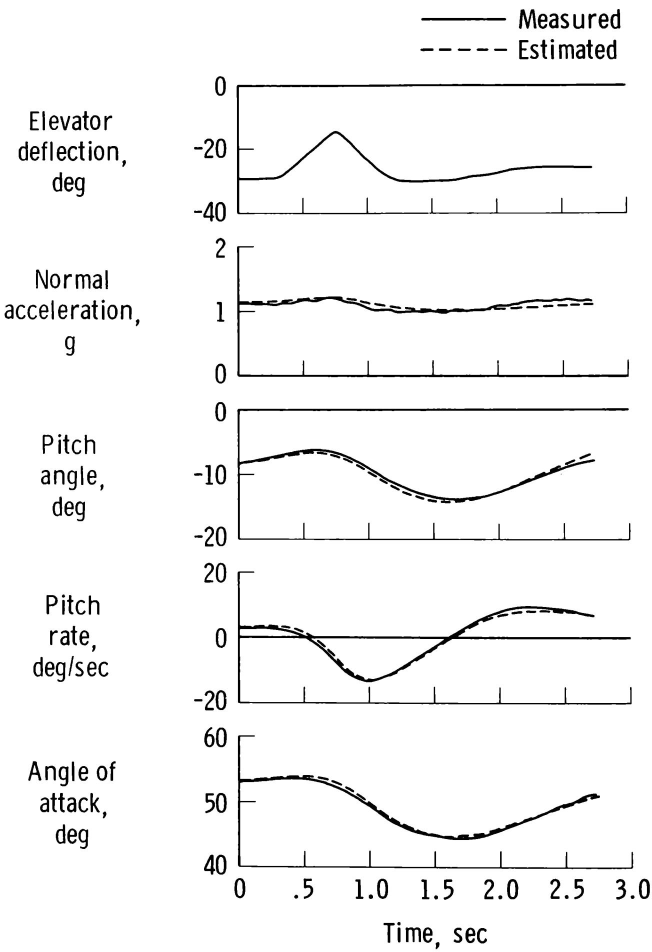


REMOTELY PILOTED RESEARCH VEHICLE FLIGHT INVESTIGATIONS

- Flight test conditions
  - Unpowered vehicle
  - All data obtained below Mach 0.6
  - No stores or approach and landing configurations investigated
- Objectives of early flights
  - Refine remotely piloted research vehicle technique
  - Obtain stability and control and performance characteristics
- Characteristics of high angle of attack tests
  - With increasing angle of attack, vehicle exhibited
    - Mild stall
    - Buffet
    - Wing rock
  - Unexpected departures did not produce spins
  - Spins were obtained only when unusual inputs were made

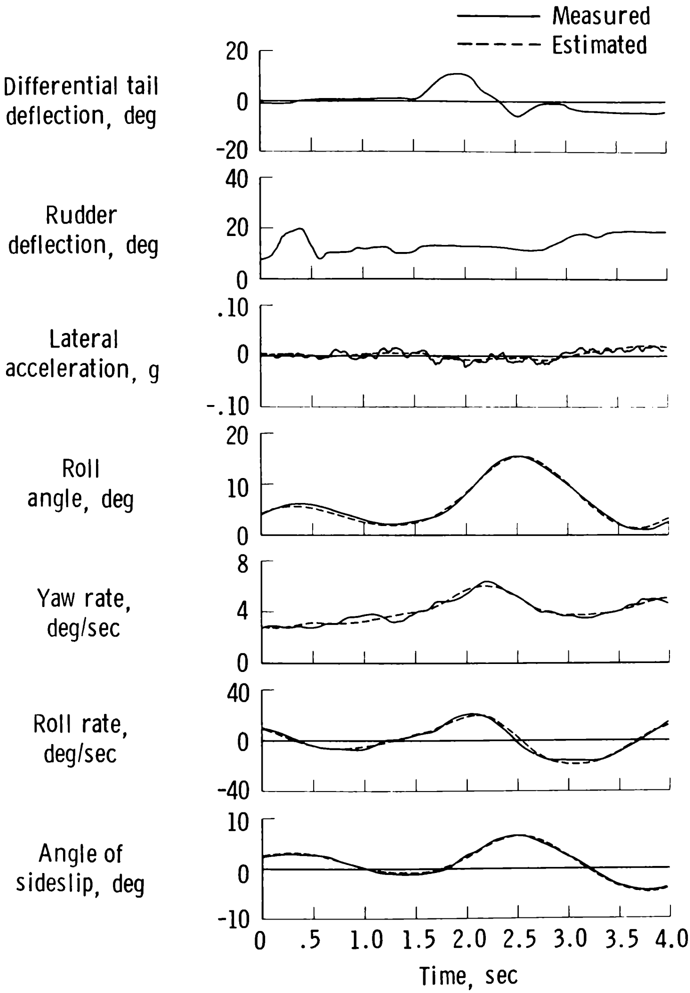
LONGITUDINAL MATCH FOR F-15 MODEL

Angle of Attack of 50°,
Center of Gravity at 38-Percent Mean Aerodynamic Chord



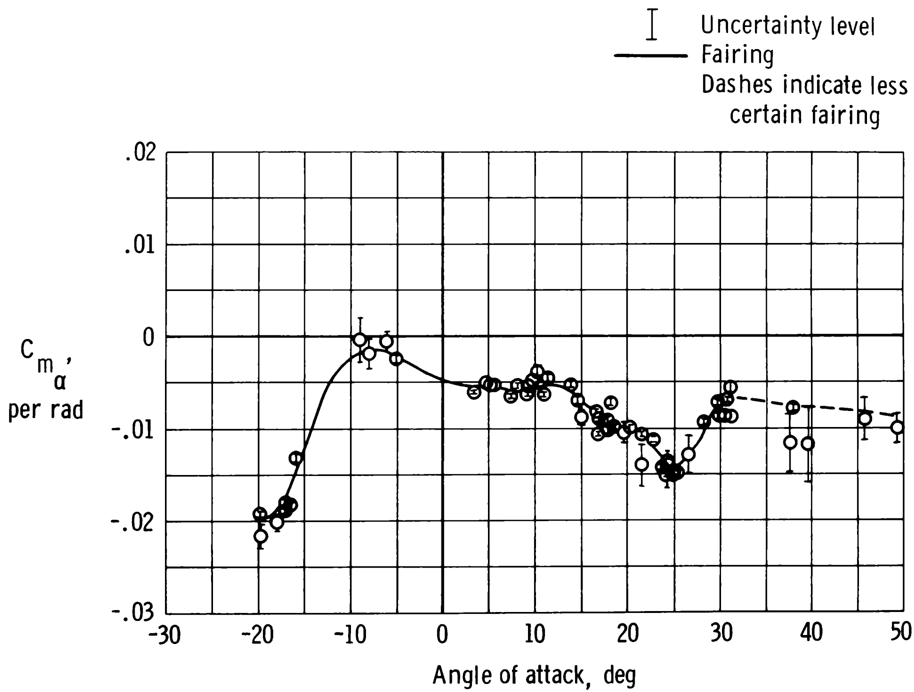
LATERAL-DIRECTIONAL MATCH FOR F-15 MODEL

Angle of Attack of 50°,
Center of Gravity at 38-Percent Mean Aerodynamic Chord



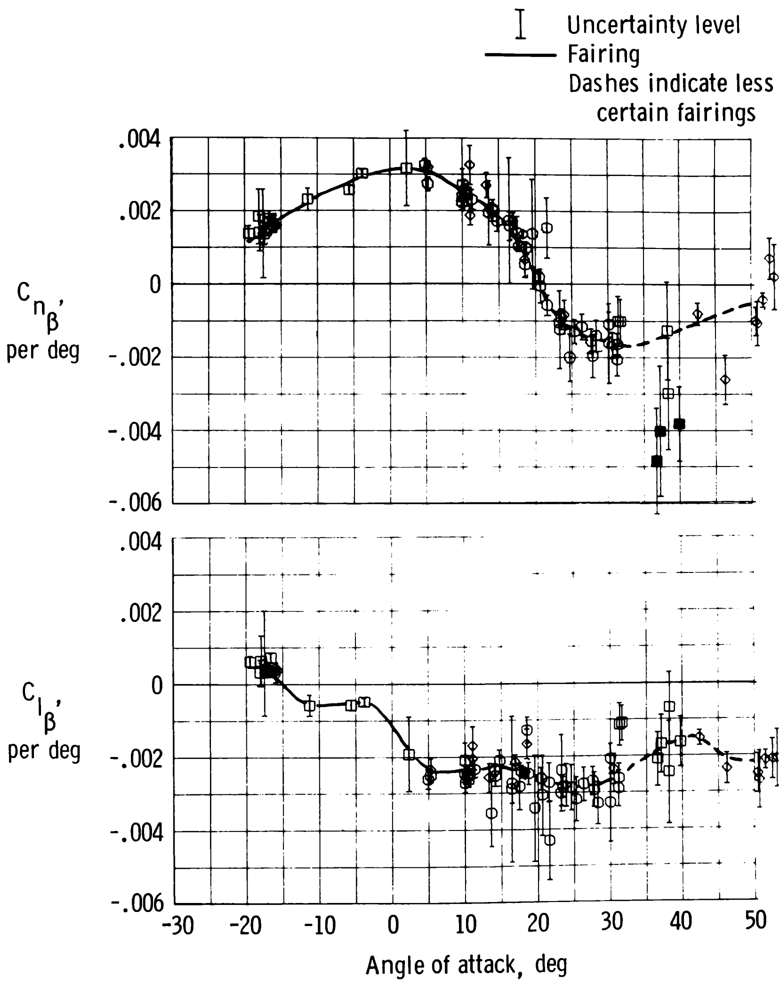
PITCHING-MOMENT SLOPE AS A FUNCTION OF ANGLE OF ATTACK

Coefficient Corrected to 26-Percent Mean Aerodynamic Chord



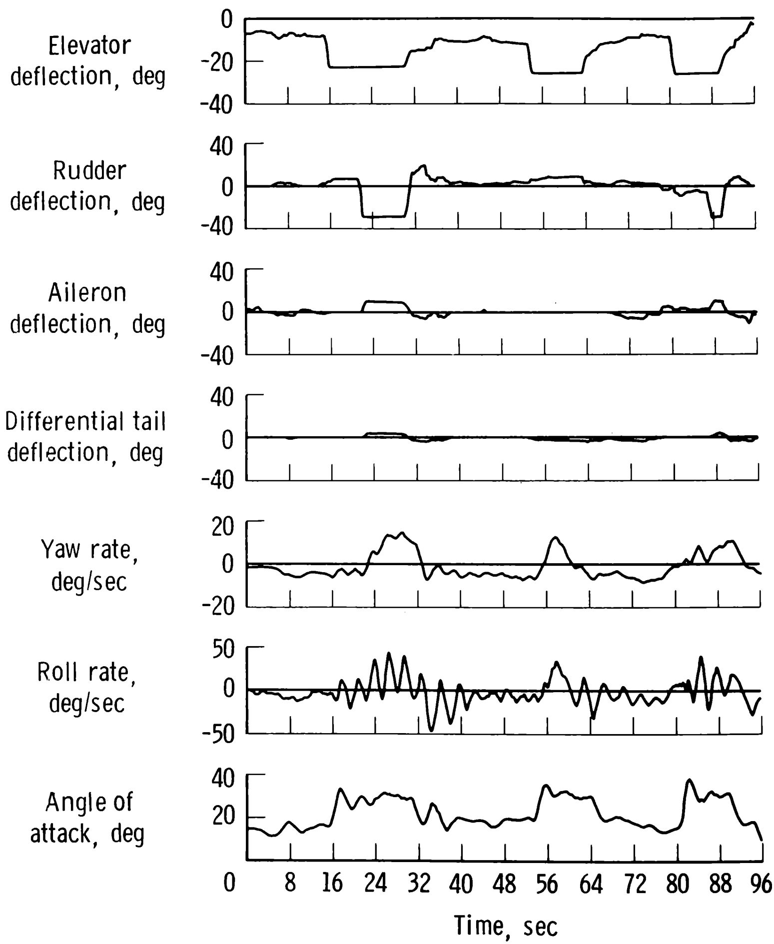
LATERAL-DIRECTIONAL MOMENT SLOPES AS FUNCTIONS OF ANGLE OF SIDESLIP (β)

Coefficient Corrected to 26-Percent Mean Aerodynamic Chord



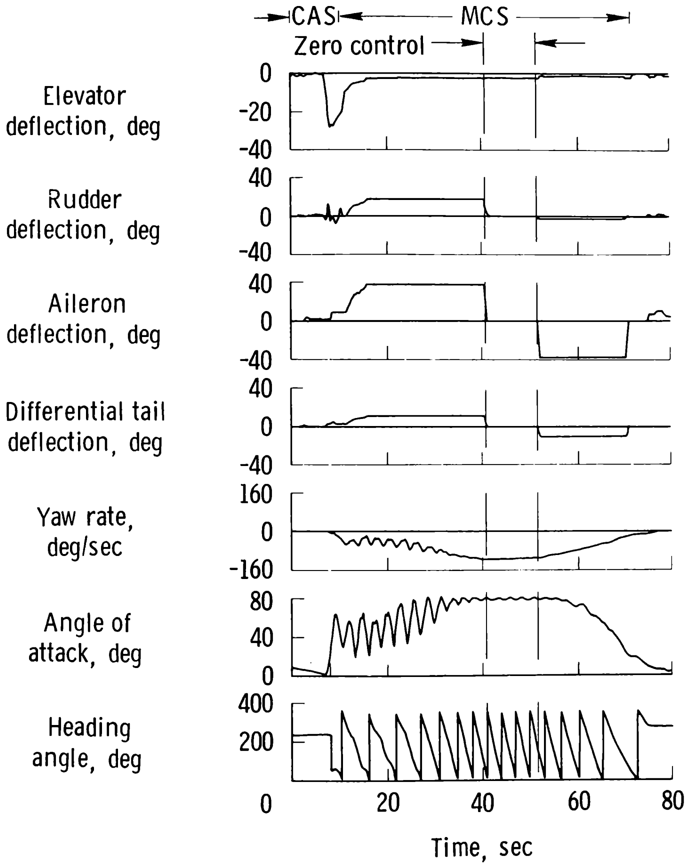
F-15 MODEL RESPONSES SHOWING SPIN RESISTANCE

Entire Maneuver in MCS;
All Units Referenced to Full Scale



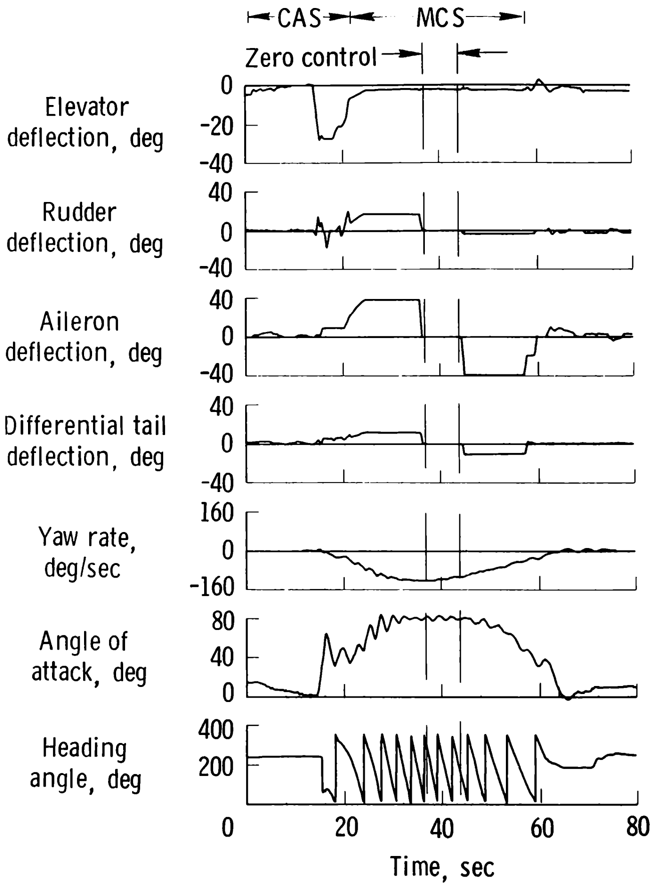
F-15 MODEL SPIN WITH OSCILLATORY ENTRY

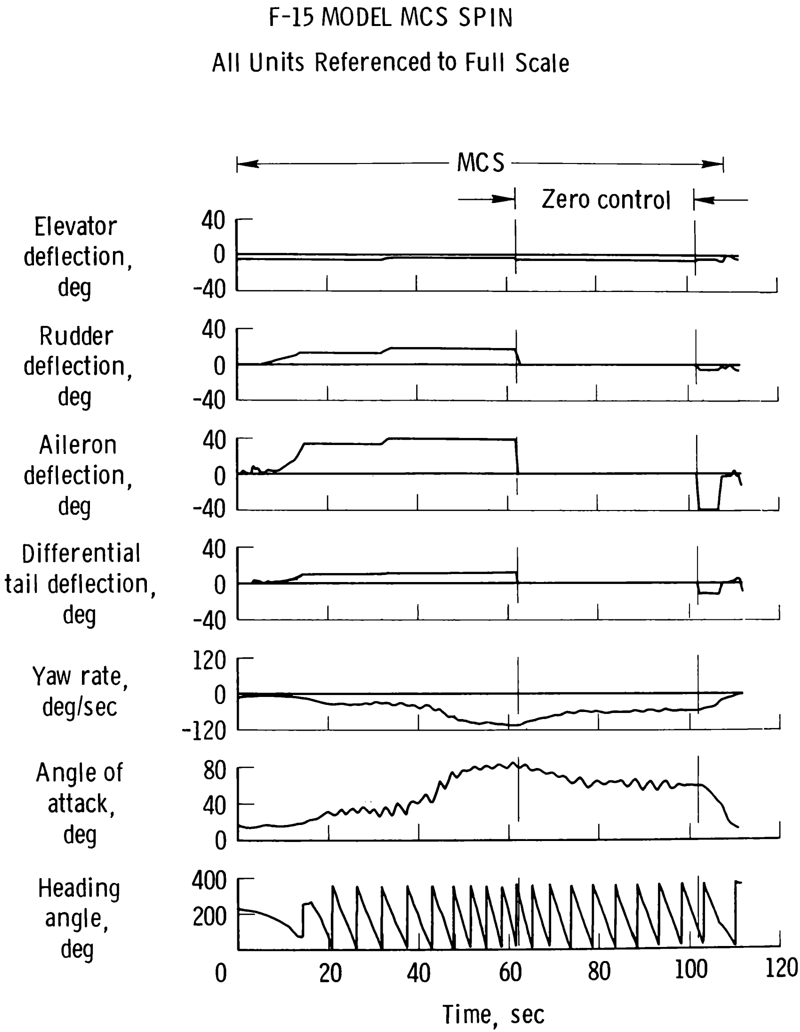
All Units Referenced to Full Scale



F-15 MODEL SPIN WITH LOW OSCILLATION ENTRY

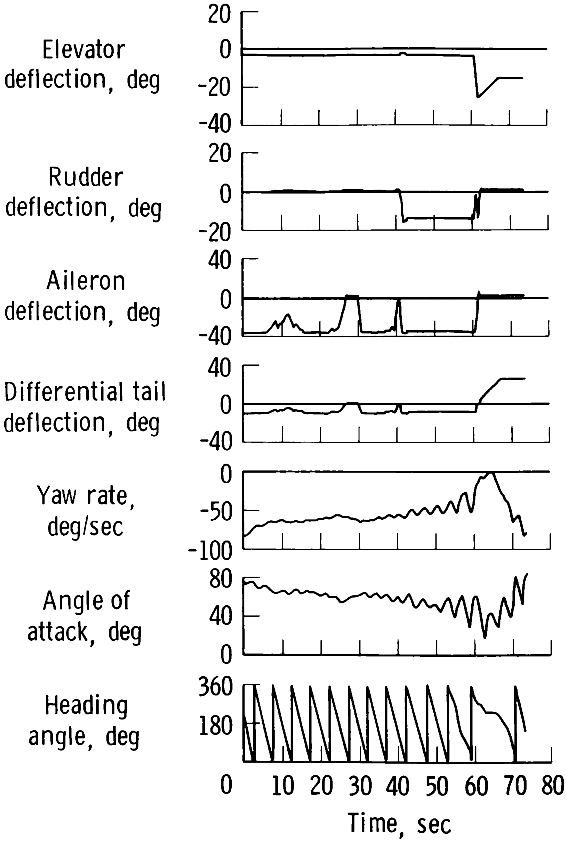
All Units Referenced to Full Scale




F-15 MODEL MCS SPIN
All Units Referenced to Full Scale
MCS
Zero control
Elevator deflection, deg
Rudder deflection, deg
Aileron deflection, deg
Differential tail deflection, deg
Yaw rate, deg/sec
Angle of attack, deg
Heading angle, deg
40
0
-40
120
-120
80
400
200
20
60
100
120
Time, sec

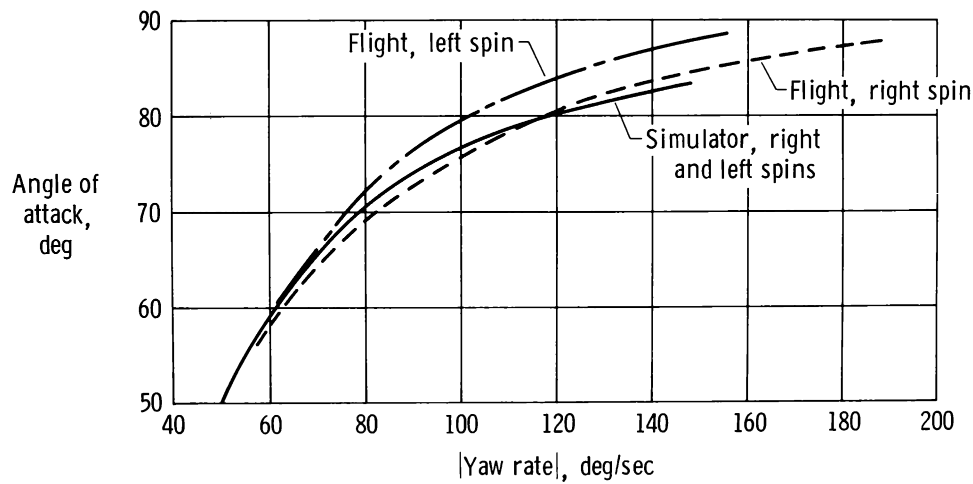
SPIN RECOVERY FOR 15,000-FOOT-POUND LATERAL OFFSET

All Units Referenced to Full Scale

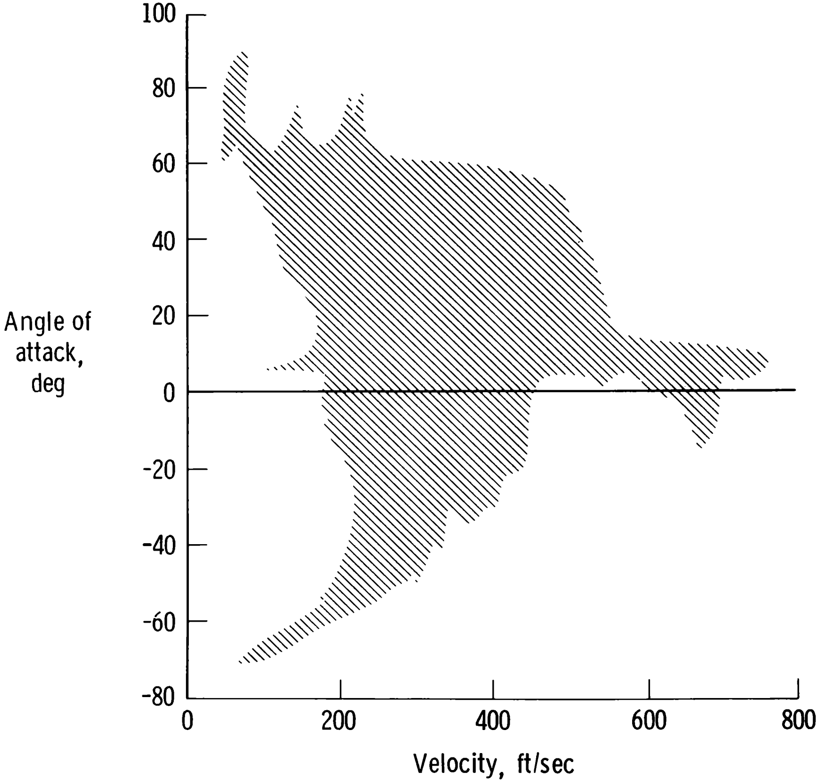


CORRESPONDENCE OF STEADY-STATE YAW RATE AND ANGLE OF ATTACK
FOR FLIGHT AND SIMULATOR DATA

Yaw Rate Referenced to Full Scale



F-15 REMOTELY PILOTED RESEARCH VEHICLE FLIGHT ENVELOPE



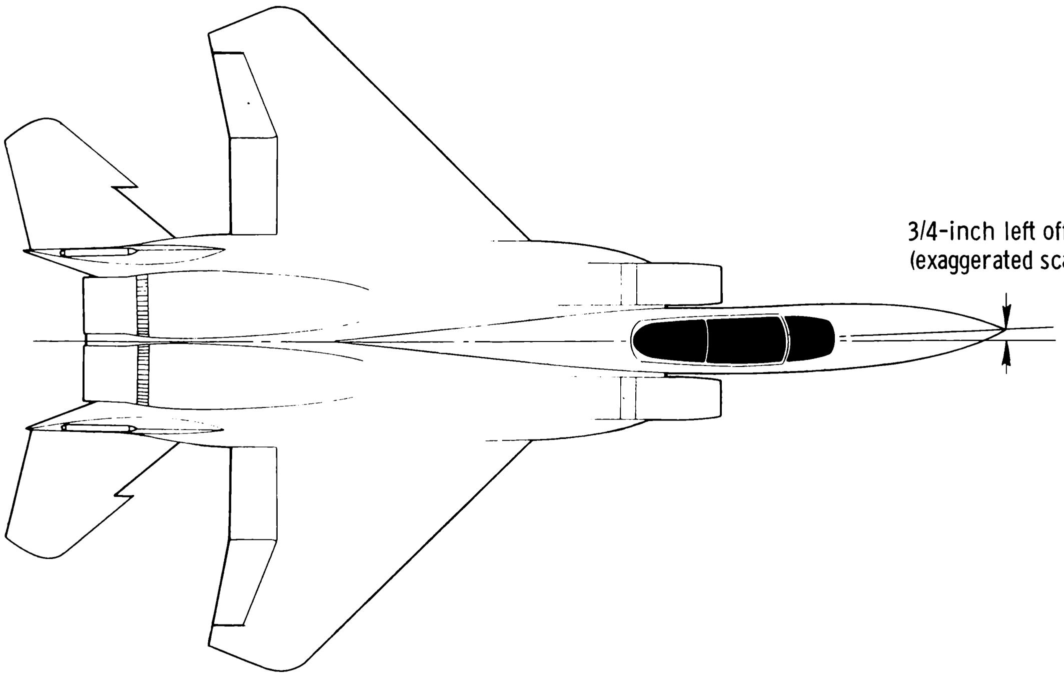
CONCLUSIONS

- Simulation studies improve data obtained from flight vehicle
- RPRV technique useful for obtaining high quality data in high risk flight regimes
- Vehicle very spin resistant
- Spins obtained show both oscillatory and smooth modes
- Spin recovery
  - Recovery controls
    - Neutralize control during spin entry
    - Apply roll control in direction of spin during spin
  - Number of turns to recovery
    - 2 to 4 for vehicle with no lateral center of gravity offset
    - 10 to 15 for vehicle with 15,000-foot-pound lateral center of gravity offset

SPIN RESEARCH

- Criteria for effects of configuration and control changes
    - Time to attain given spin rate for given entry technique
    - Maximum spin rate
    - Zero control smooth modes
    - Number of turns to recovery from zero control mode
- Configuration studies
    - Nose shape and symmetry
    - Control system changes
    - Pilot-initiated "automatic" spin recovery

F-15 MODEL LATERAL ASYMMETRY

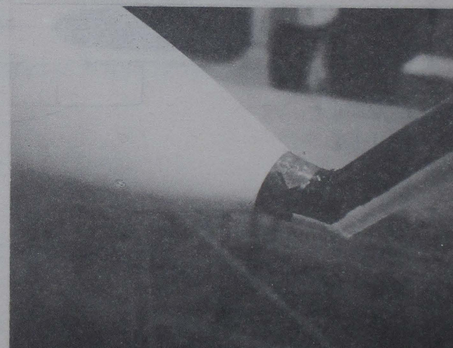


TAPE CONTOURS AT JUNCTION OF NOSE AND NOSE BOOM

3/8-Scale F-15 Model

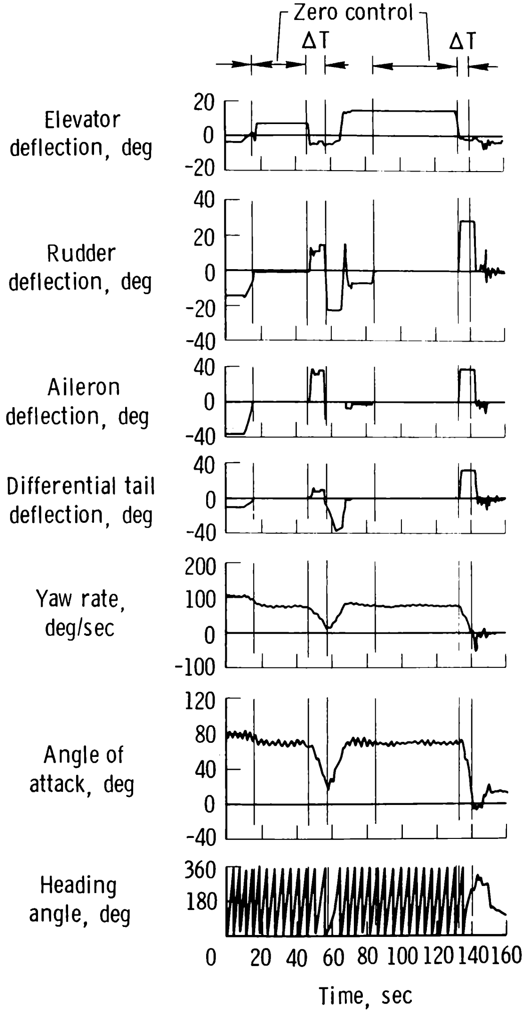
Left side

Right side



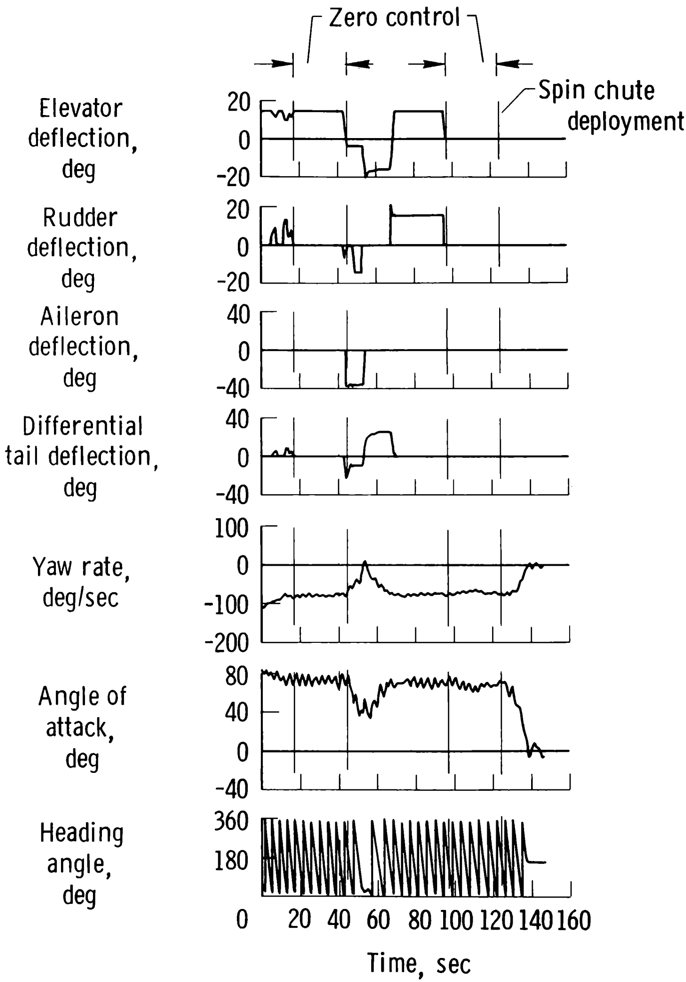
SMOOTH MODE SPIN AND RECOVERIES

All Units Referenced to Full Scale



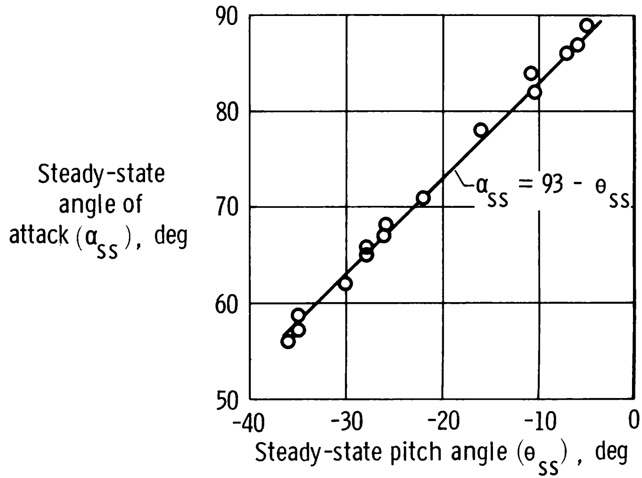
SMOOTH MODE SPIN AND RECOVERIES

All Units Referenced to Full Scale



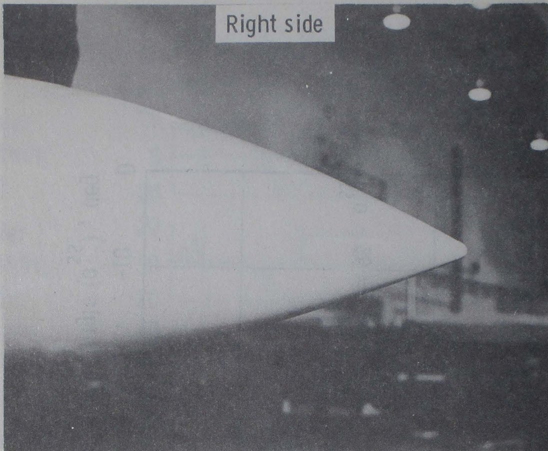
COMPARISON OF STEADY-STATE ANGLE OF ATTACK WITH STEADY-STATE PITCH ANGLE

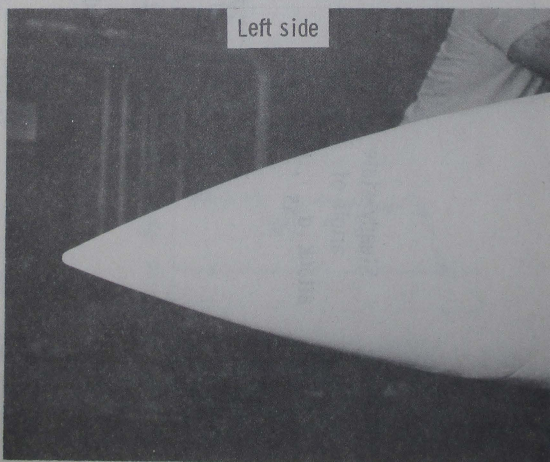
3/8-Scale F-15 Model in Spin



F-15 MODEL NOSE IN PRODUCTION CONFIGURATION

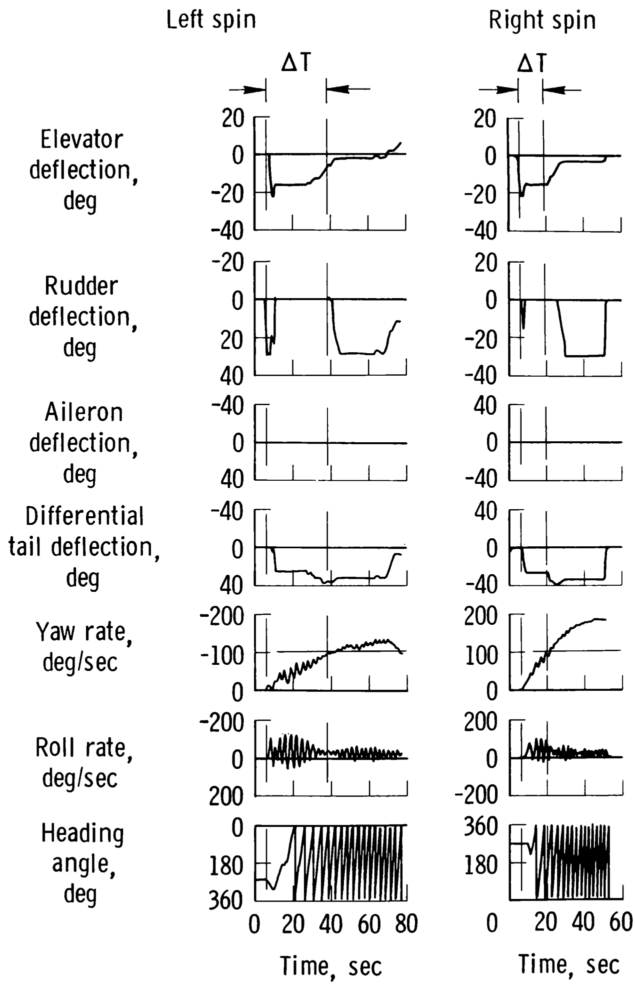
3/8-Scale Model





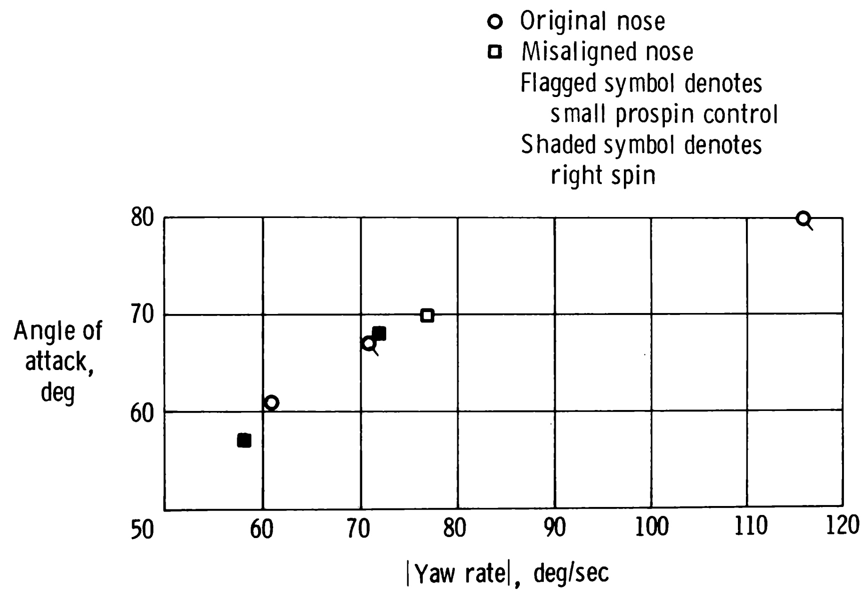
COMPARISON OF SPIN ENTRIES WITHOUT NOSE BOOM

All Units Referenced to Full Scale



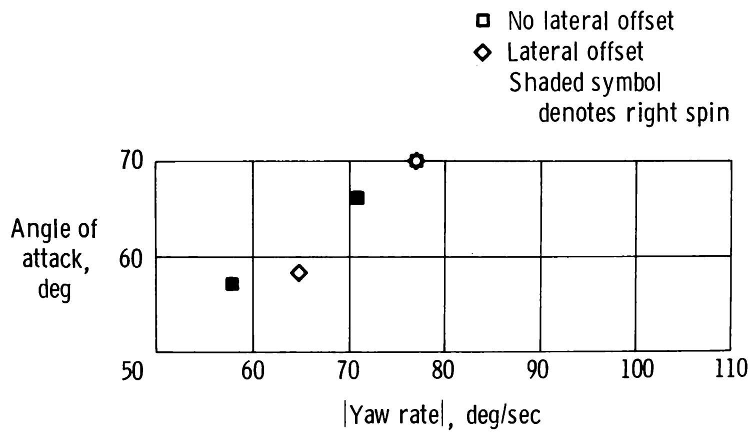
COMPARISON OF ZERO CONTROL SMOOTH SPIN MODES
FOR ORIGINAL AND MISALIGNED NOSE

3/8-Scale F-15 Model, Nose Boom On,
Yaw Rate Referenced to Full Scale



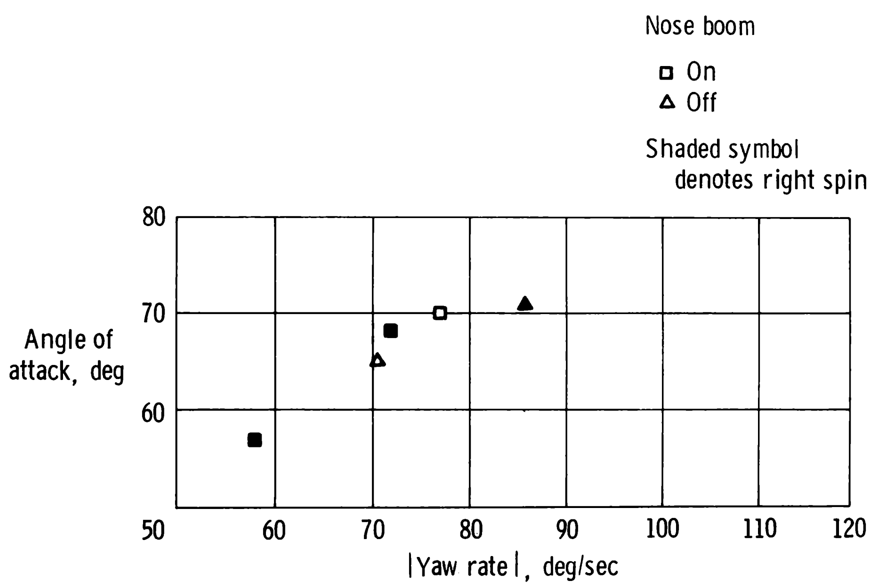
COMPARISON OF ZERO CONTROL SMOOTH SPIN MODES WITH AND WITHOUT LATERAL OFFSET

3/8-Scale F-15 Model, Misaligned Nose, Nose Boom On, Yaw Rate Referenced to Full Scale



COMPARISON OF ZERO CONTROL SMOOTH SPIN MODES FOR NOSE BOOM ON AND OFF

Misaligned Nose, All Units Referenced to Full Scale



MAXIMUM SPIN RATES

Yaw Rate Referenced to Full Scale

Nose boom	Yaw rate, deg/sec	
	Left spin	Right spin
On	120	190
Off	130	200

FUTURE RESEARCH

- Additional tests for data correlation
    - Standard wind tunnel
    - Spin tunnel
    - Rotary balance tunnel
- Further documentation of vehicle stall/spin characteristics
    - Pressure distributions
    - Tufts aft of vehicle nose
- Additional configuration studies
    - Control studies
        - Effects of spin and recovery characteristics on control system characteristics
        - Spin avoidance
        - Pilot initiated "automatic" spin recovery
    - Configuration changes
        - Align nose
        - Modify nose shape

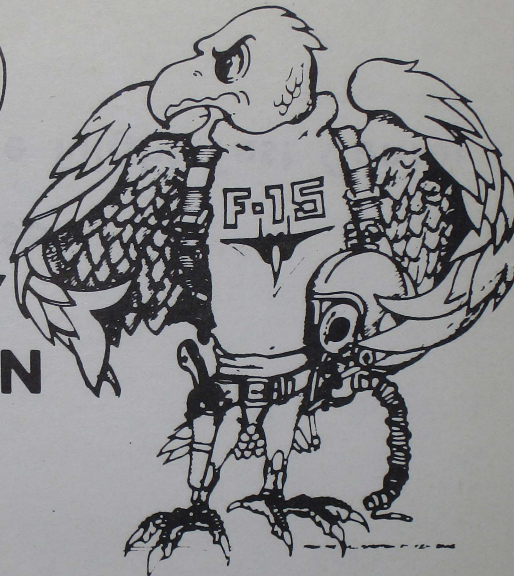
CONCLUSIONS

- Zero control smooth spin modes can be accurately obtained with the remotely piloted research vehicle
- Smooth spin modes change with nose shape
- Misaligned nose
  - Causes vehicle to spin more readily to the right
  - Smooth spin modes are different for left and right spins

FULL SCALE F-15 SPIN TESTS

Don Wilson
Air Force Flight Test Center

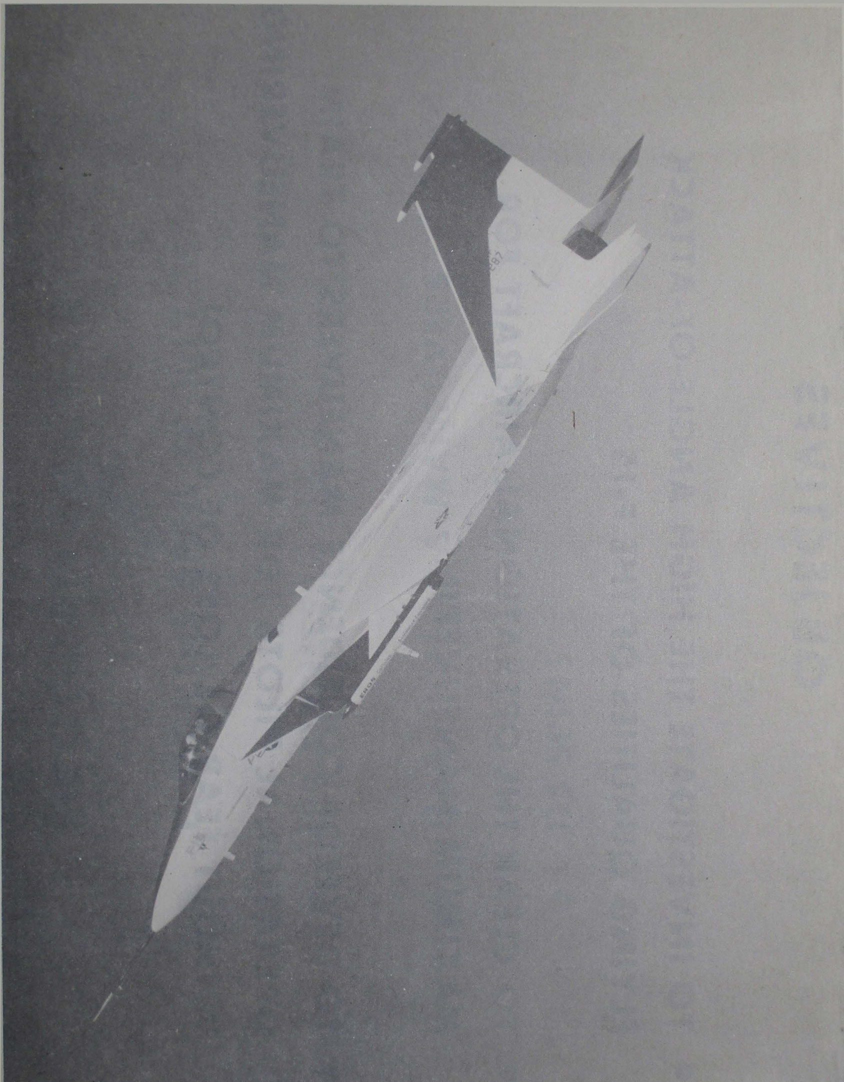
F-15



STALL/POST-STALL/ SPIN INVESTIGATION

AIR FORCE SYSTEMS COMMAND

AD INEXPLORATA



OBJECTIVES

- TO INVESTIGATE THE HIGH ANGLE-OF-ATTACK FLYING QUALITIES OF THE F-15
- TO CLEAR THE OPERATIONAL AIRCRAFT FOR MAXIMUM MANEUVERING
- TO DEVELOP CONFIDENCE MANEUVERS TO TRAIN OPERATIONAL PILOTS FOR MAXIMUM MANEUVERING WITHOUT FEAR OF LOSS OF CONTROL

PROGRAM SUMMARY

- 15 MONTHS APRIL 74-JULY 75
- 189 FLIGHTS
- 1164 HIGH AOA MANEUVERS
- 115 SPINS

6-104

UNIQUE TEST SYSTEMS

- SPIN RECOVERY PARACHUTE
- EMERGENCY HYDRAULIC
- EMERGENCY ELECTRICAL
- COCKPIT SPECIAL FEATURES
- CAMERAS
- HIGH VISIBILITY PAINT SCHEME

TEST PHASES

MIL-S-83691A

- STALLS
- STALLS WITH AGGRAVATED INPUTS
- STALLS WITH AGGRAVATED AND SUSTAINED INPUTS
- SPIN ATTEMPTS

6-106

MODIFICATIONS

- ROLL CAS CUT-OFF AT 20.33° AOA
- SPEEDBRAKE AUTO RETRACT
- ARI FAST TURN-ON
- 60°/SEC YAW RATE/FULL LATERAL CONTROL AUTHORITY - SPIN RECOVERY AID
- 30°/SEC YAW RATE TONE - DEPARTURE TONE
- POWER APPROACH SLOW SPEED WARNING
- SYMMETRIC WING FUEL TRANSFER

STALLS

- BUFFET - LIGHT FOLLOWED BY MODERATE
- WING ROCK - AMPLITUDE INCREASING TO FULL AFT STICK
- FULL AFT STICK - 34 to 40 DEGREES ANGLE OF ATTACK (45-50 UNITS), LESS ABOVE 0.8 MACH NUMBER
- LATERAL ASYMMETRIES - YAW AWAY FROM HEAVY WING ABOVE 30 UNITS ANGLE OF ATTACK, SEVERITY INCREASING WITH INCREASED ANGLE OF ATTACK, AMOUNT OF ASYMMETRY AND INCREASED SPEED

DEPARTURES

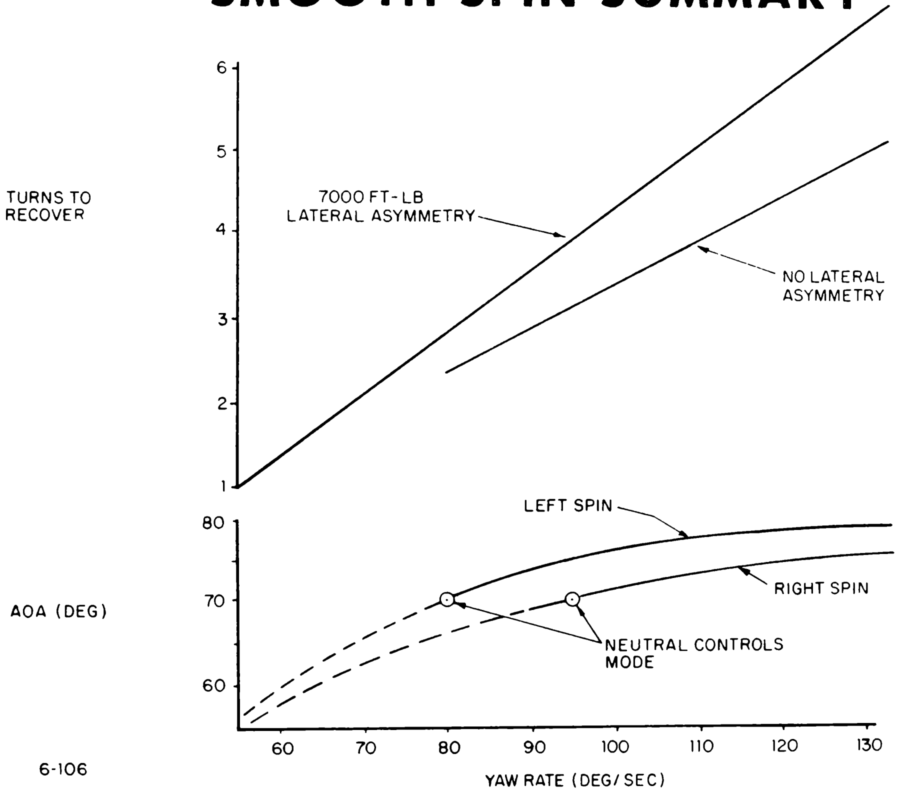
- LATERALLY SYMMETRIC AIRPLANE RESISTANT TO DEPARTURE BUT NOT DEPARTURE FREE
- YAW EXCURSIONS AT 31-34 DEGREES ANGLE OF ATTACK (40-45 UNITS) AT 0.5-0.75 MACH NO.
- LATERAL ASYMMETRIES - YAW BUILDUP ABOVE 35 UNITS ANGLE OF ATTACK, NO LONGER CONTROLLABLE WITH LATERAL-DIRECTIONAL CONTROLS
- RECOVERY - NEUTRAL CONTROLS AT DEPARTURE
- AUTO ROLLS - "RUDDER AGAINST" RECOVERY

SPINS

- LATERALLY SYMMETRIC AIRPLANE SPIN RESISTANT
- LATERAL ASYMMETRIES DECREASE SPIN RESISTANCE
- MODES
  - ERECT SMOOTH
  - ERECT HIGHLY OSCILLATORY
  - INVERTED
- RECOVERY
  - ERECT SMOOTH SPIN REQUIRES "LATERAL WITH" TO RECOVER
  - OTHERS RECOVER WITH NEUTRAL CONTROLS
  - LATERAL ASYMMETRIES INCREASE TURNS TO RECOVER

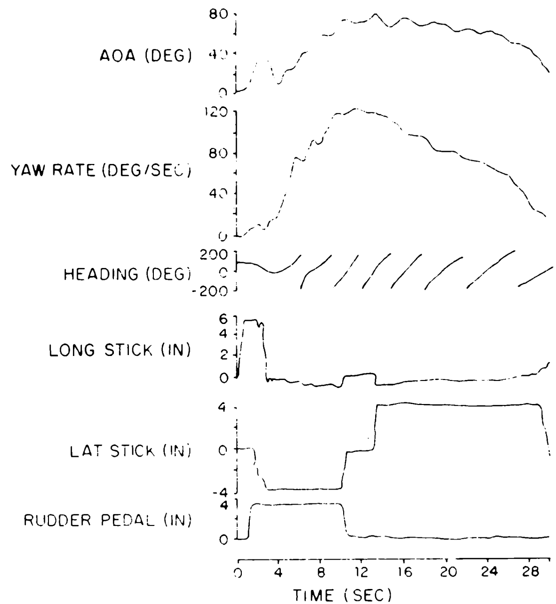
5-314

SMOOTH SPIN SUMMARY

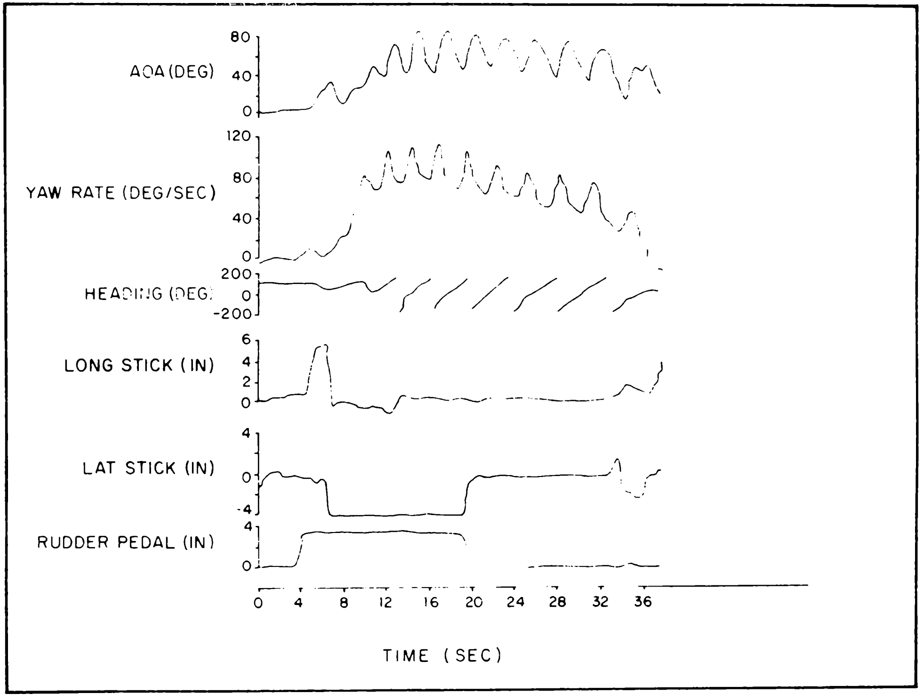


6-106

SMOOTH SPIN


AOA (DEG)
80
40
0
YAW RATE (DEG/SEC)
120
80
40
0
HEADING (DEG)
200
0
-200
LONG STICK (IN)
6
4
2
0
LAT STICK (IN)
4
0
-4
RUDDER PEDAL (IN)
4
0
0
4
8
12
16
20
24
28
TIME (SEC)

HIGHLY OSCILLATORY SPIN



6-107

RECOMMENDED HANDBOOK RECOVERY PROCEDURE

- AIRPLANE OUT-OF-CONTROL (DEPARTURE TONE) - NEUTRALIZE CONTROLS
- IF NO RECOVERY - RUDDER AGAINST ROTATION (AGAINST TURN NEEDLE)
- IF NO RECOVERY (TONE PERSISTS) - FULL LATERAL STICK WITH ROTATION (WITH TURN NEEDLE)
- AIRPLANE RECOVERED (TONE CEASES) - NEUTRALIZE CONTROLS

CONFIDENCE MANEUVERS

- MANEUVERS INVOLVING SEQUENCED CONTROL INPUTS
  - ROLLS PLUS AFT STICK
  - AFT STICK PLUS LATERAL CONTROL
  - AFT STICK, RUDDER AND LATERAL CONTROL
- ONE-G AND ACCELERATED STALLS
- AUTO ROLLS
- DECELERATING TURNS AT 40-45 UNITS AOA
- TAIL SLIDES
- HIGH PITCH ATTITUDE, HIGH AOA
- INVERTED STALLS

MANEUVERING LIMITATIONS

- 30 UNITS
  - POWER APPROACH CONFIGURATION
  - AIR-TO-GROUND STORES EXCEPT SUU-20
  - FULL OR PARTIALLY FULL EXTERNAL TANKS
  - LATERAL ASYMMETRIES EXCEEDING 10,000 FT-LBS
- NO INTENTIONAL SPINS
- INTENTIONAL DEPARTURES TO DEPARTURE TONE ONLY

CONCLUSIONS

- WITH THE RECOMMENDED MODIFICATIONS THE F-15 IS:
  - DEPARTURE RESISTANT WITH EXTERNAL STORE LATERAL ASYMMETRIES OF 5,000 FT-LB OR LESS
  - SPIN RESISTANT WITH LATERAL ASYMMETRIES OF 10,000 FT-LB
  - DEPARTURE RECOVERABLE WITH NEUTRAL CONTROLS AT DEPARTURE TONE WITH LATERAL ASYMMETRIES OF 10,000 FT-LB OR LESS (EXCEPT AUTO ROLLS)
  - SPIN RECOVERABLE WITH LATERAL ASYMMETRIES TO 7,000 FT-LB

5-317

CORRELATION OF TESTING TECHNIQUES AND SUMMARY

Skip Hickey

USAF Aeronautical Systems Division

and

Jim Bowman

NASA Langley Research Center

13% RC DROP MODEL

- CG RANGE EVALUATED - 26% TO 28.5% MAC
- INERTIALLY SCALED FOR SPINS AT HIGH ALTITUDE
- INLETS BLOCKED AND FIXED IN THE 11° DOWN MODE
- BASELINE WING TIPS
- BOTH CAS AND MECHANICAL AUTHORITIES BASED ON TRIM
- ANGLE OF ATTACK
- NO FEEDBACK LOOPS

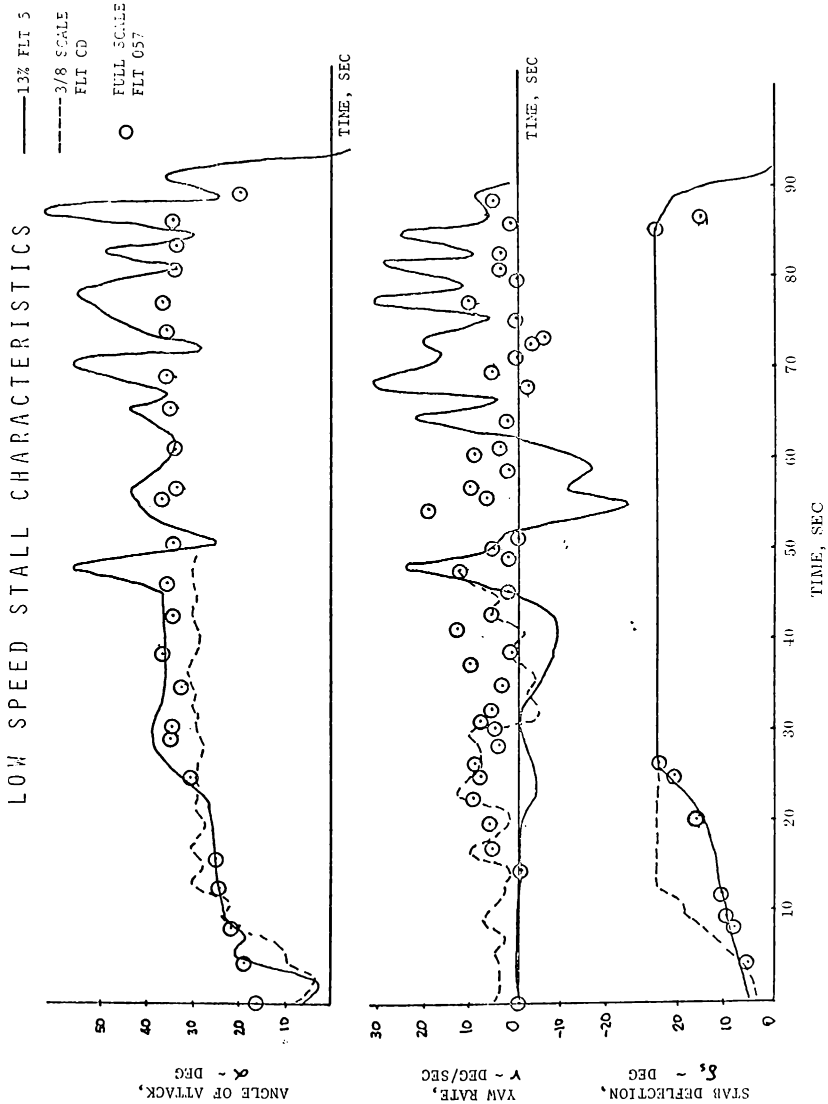
3/8 SCALE RPRV

- CG RANGE EVALUATED @ 26% AND 30.3% MAC
- INERTIALLY SCALED FOR SPINS AT MODERATE ALTITUDE
- INLETS BLOCKED AND FIXED IN THE 11° DOWN MODE
- BOTH BASELINE AND RAKED TIPS EVALUATED
- AUGMENTATION SYSTEM MORE FULLY REPRESENTED

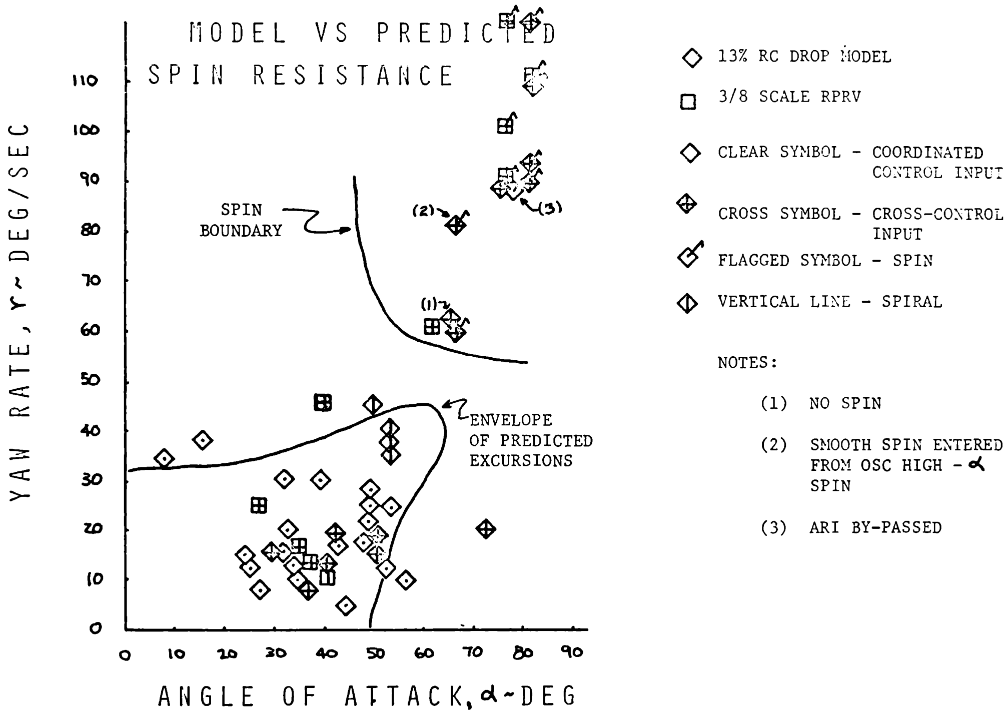
- DEPARTURE MANEUVERS EVALUATED INCLUDED:

	13%	3/8	F-8
GRADUAL STALLS		✓	✓
ACCELERATED STALLS	✓	✓	✓
HIGH AOA ROLL WITH LATERAL STICK	✓	✓	✓
HIGH AOA RUDDER ROLLS	✓	✓	✓
FULL AFT STICK + PRO SPIN RUDDER	✓	✓	✓
FULL AFT STICK + CROSS CONTROLS	✓	✓	✓
ROLLING PULLUP WITH CROSS CONTROL	✓	✓	✓
AUGER ROLLS		✓	✓
ZERO AIRSPEED WITH FULL LATERAL CONTROL			✓
TAIL SLIDES WITH FULL LATERAL CONTROL			✓

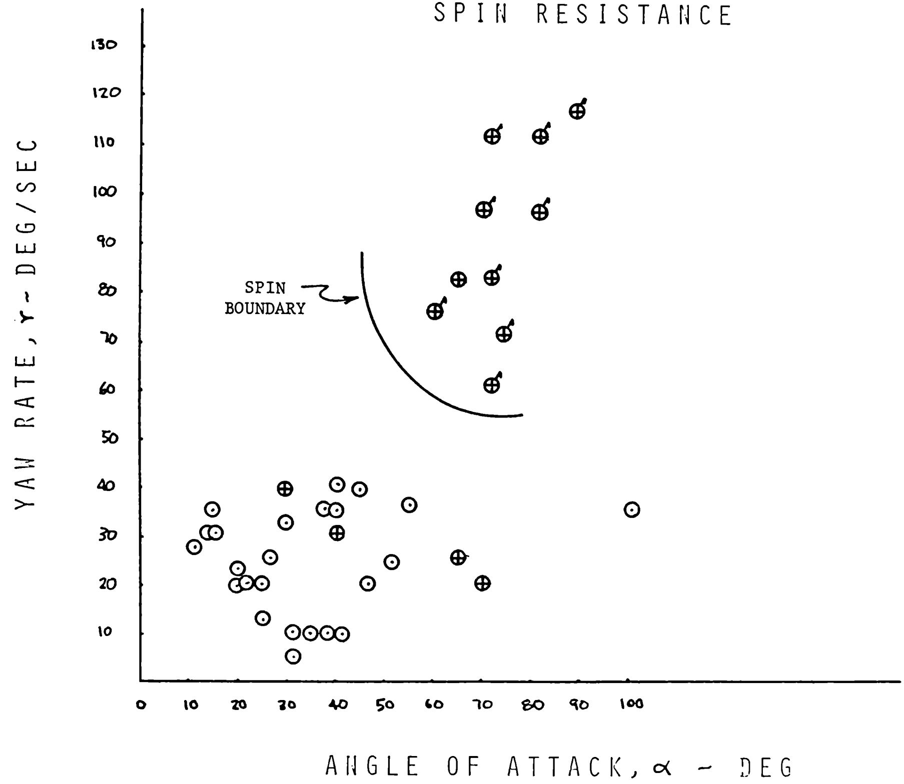
- NO SPINS RESULTED



LOW SPEED STALL CHARACTERISTICS
13% FLT 5
3/8 SCALE FLT CD
FULL SCALE FLT 057
ANGLE OF ATTACK, α ~ DEG
YAW RATE, r ~ DEG/SEC
STAB DEFLECTION, δ_s ~ DEG
TIME, SEC
TIME, SEC
TIME, SEC
10
20
30
40
50
60
70
80
90


MODEL VS PREDICTED
SPIN RESISTANCE
YAW RATE, r ~ DEG/SEC
ANGLE OF ATTACK, α ~ DEG
0
10
20
30
40
50
60
70
80
90
100
110
SPIN BOUNDARY
ENVELOPE OF PREDICTED EXCURSIONS
(1)
(2)
(3)
13% RC DROP MODEL
3/8 SCALE RPRV
CLEAR SYMBOL - COORDINATED CONTROL INPUT
CROSS SYMBOL - CROSS-CONTROL INPUT
FLAGGED SYMBOL - SPIN
VERTICAL LINE - SPIRAL
NOTES:
(1) NO SPIN
(2) SMOOTH SPIN ENTERED FROM OSC HIGH - α SPIN
(3) ARI BY-PASSED

FULL SCALE VS PREDICTED
SPIN RESISTANCE



MODEL RESULTS INDICATED:

- THE MODEL WAS SPIN RESISTANT WITH COORDINATED AND CROSS CONTROLLED INPUTS
- RESULTING YAW RATE EXCURSIONS WERE NOT DIVERGENT WITH FULL AFT STICK
- RECOVERY FROM DEPARTURE AND FORCED POST STALL GYRATIONS WAS POSITIVE WHEN CONTROLS WERE NEUTRALIZED

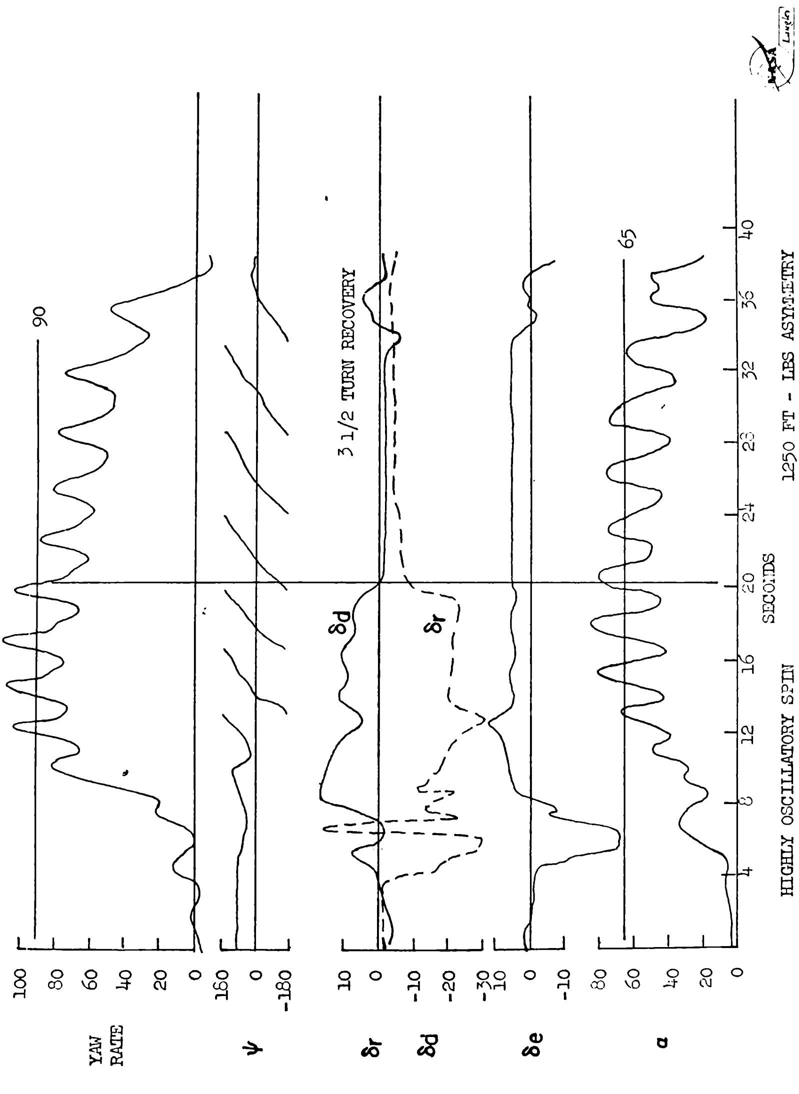
FLIGHT TEST RESULTS

DEPARTURES

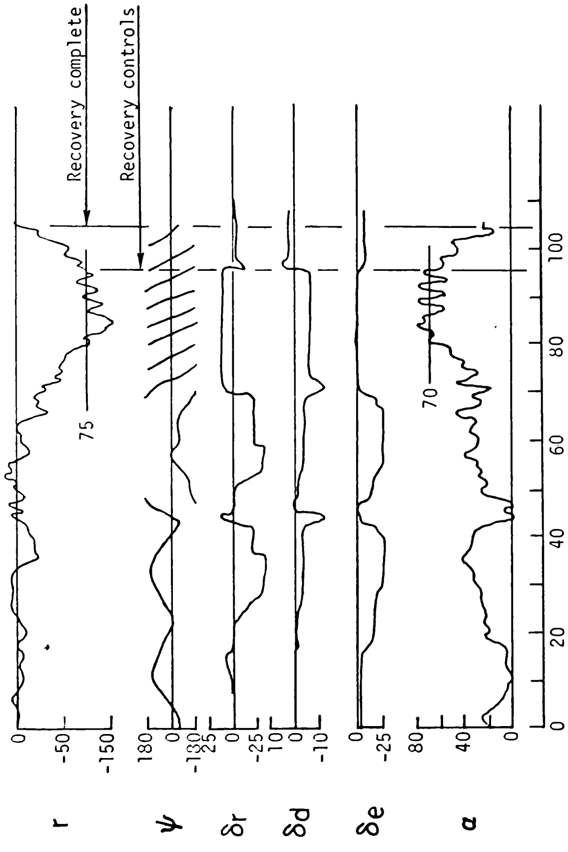
- RECOVERY - NEUTRAL CONTROLS AT DEPARTURE
- AUTO ROLLS - "RUDDER AGAINST" RECOVERY
- YAW RATE - KEY PARAMETER IN PROGRESSION TO SPIN

CORRELATION OF MODELS AND FULL SCALE

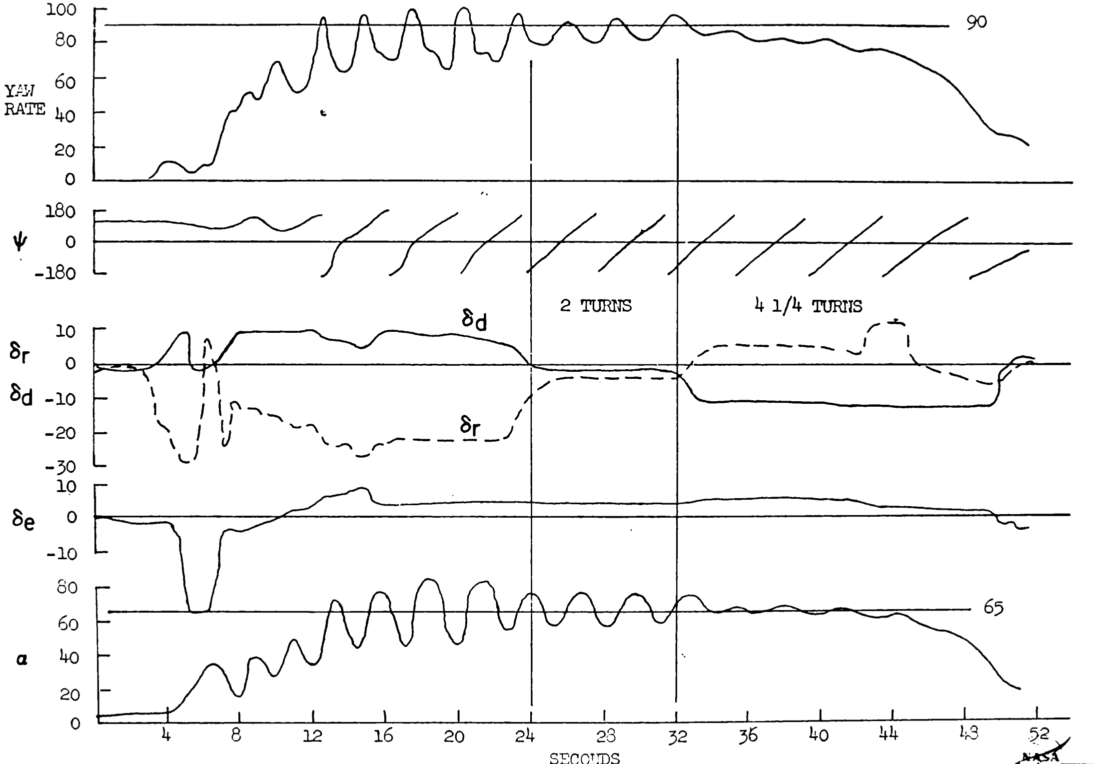
SPIN MODES	SPIN TUNNEL	13% DROP MODEL	3/8 RPRV	FULL SCALE
Oscillatory	α, deg = 55 - 75	40 - 75	40 - 80	45 - 80 60 - 80 50 - 70
	Ω, sec/turn = 4 - 5	4 - 5	4 - 5	4 - 5
	Rec. by $\delta a, \delta r$ = 1, 2	$\frac{1}{2}$, $2\frac{1}{4}$	NA	$2\frac{1}{2}$
Smooth High α	α, deg = 80	80	75 - 80	70 - 80
	Ω, sec/turn = 2 - 3	3 - 4	3.5 - 3	3
	Rec. by $\delta a, \delta r$ = 4, 5	$3\frac{1}{2}$	4, 5	$3\frac{1}{2}$, 5
δ's → 0	α, deg = 65	60	55 - 60	65 - 70
	Ω, sec/deg = 4.3	5	5	4 - 3.5
	Rec. by $\delta a, \delta r$ = -	2	2	$3\frac{1}{2}$, 3



HIGHLY OSCILLATORY SPIN
1250 FT - LBS ASYMMETRY
3 1/2 TURN RECOVERY
SECONDS
YAW RATE
ψ
δr
δd
δe
α
90
65

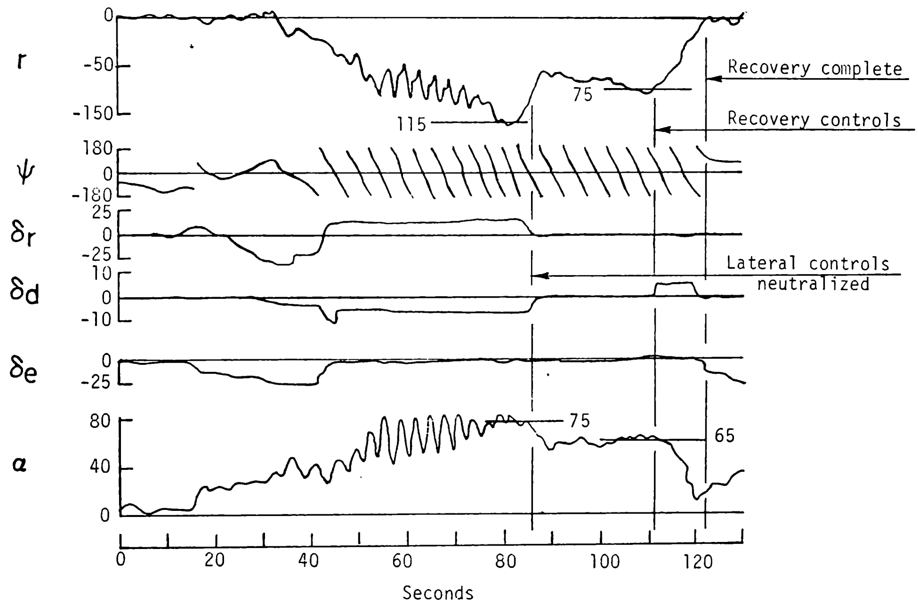


OSCILLATORY SPIN

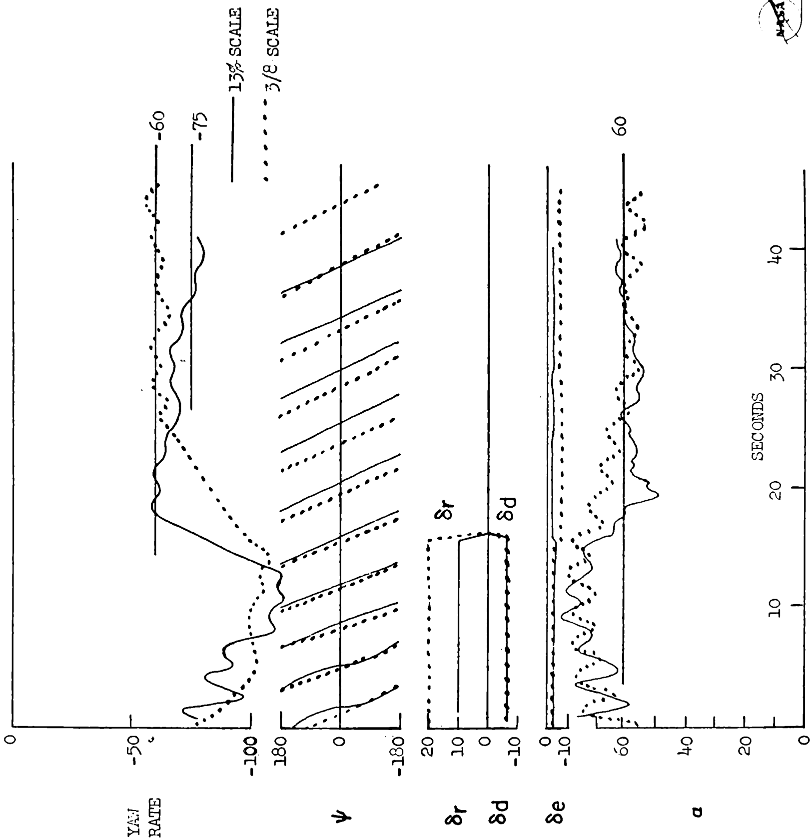


HIGHLY OSCILLATORY SPIN

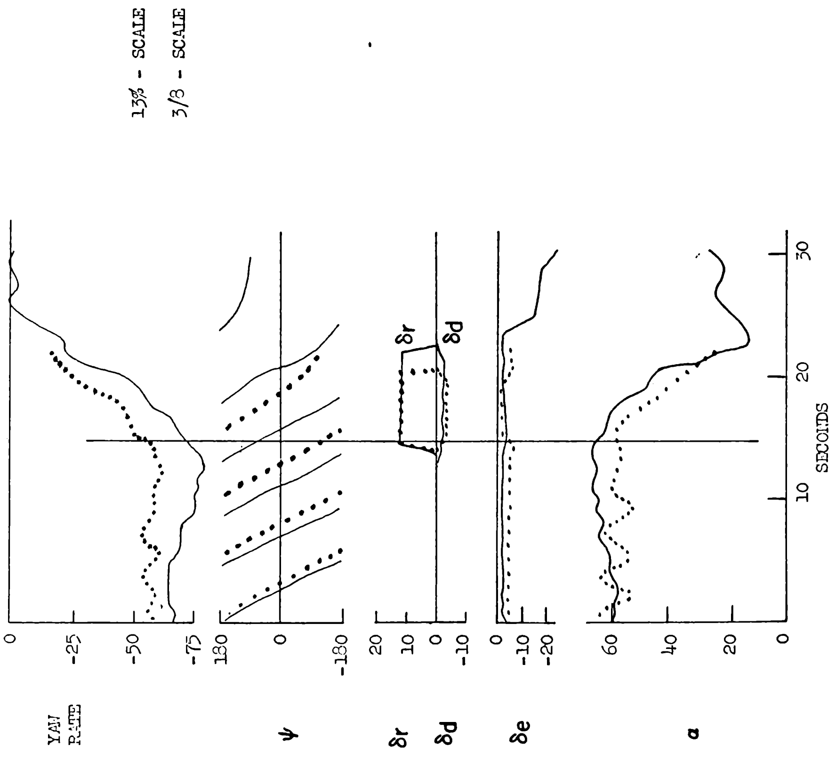
1250 FT - LBS ASYMMETRY

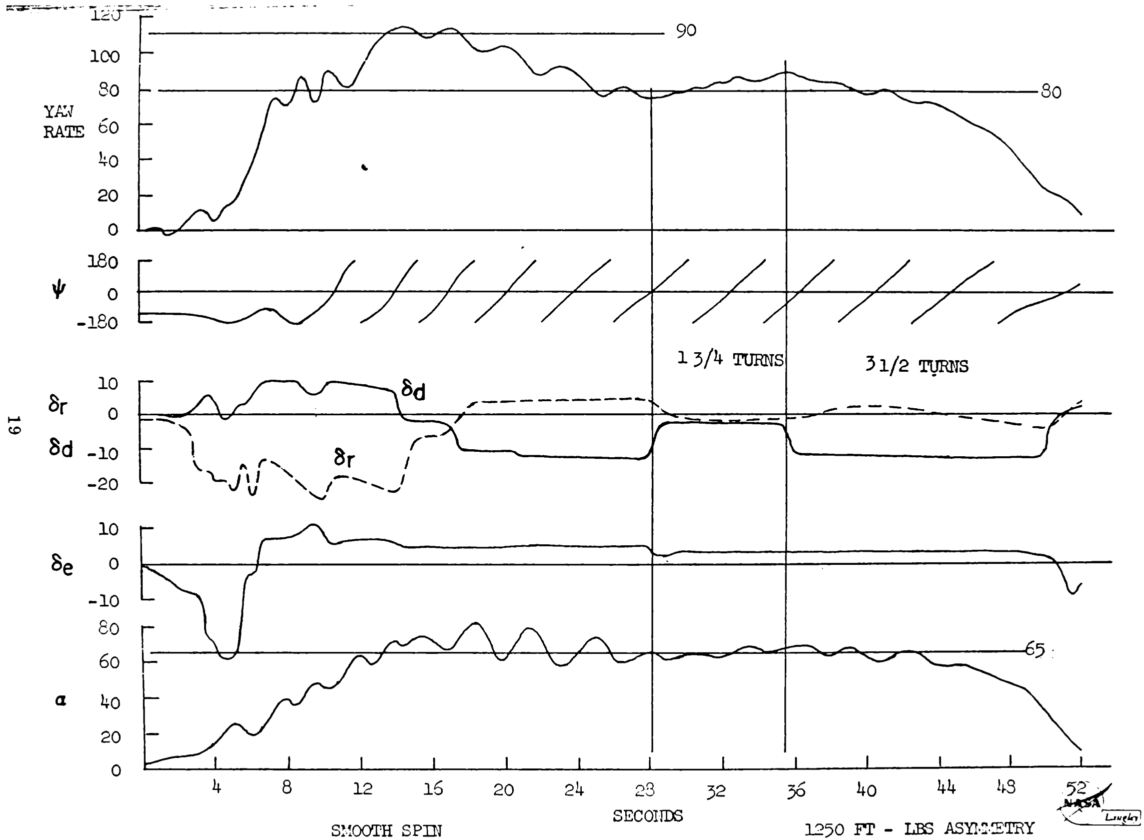


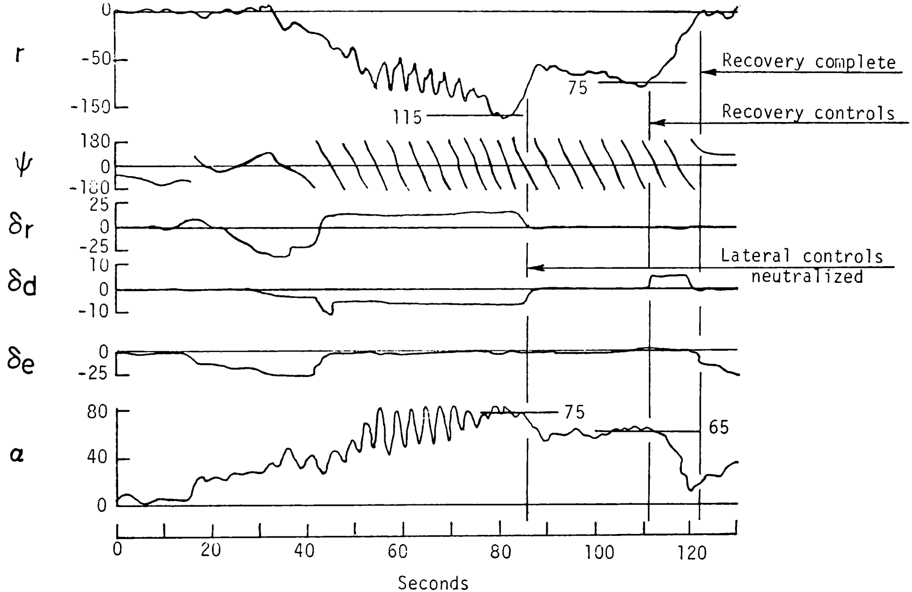
HIGH-α SPIN AND SMOOTH SPIN



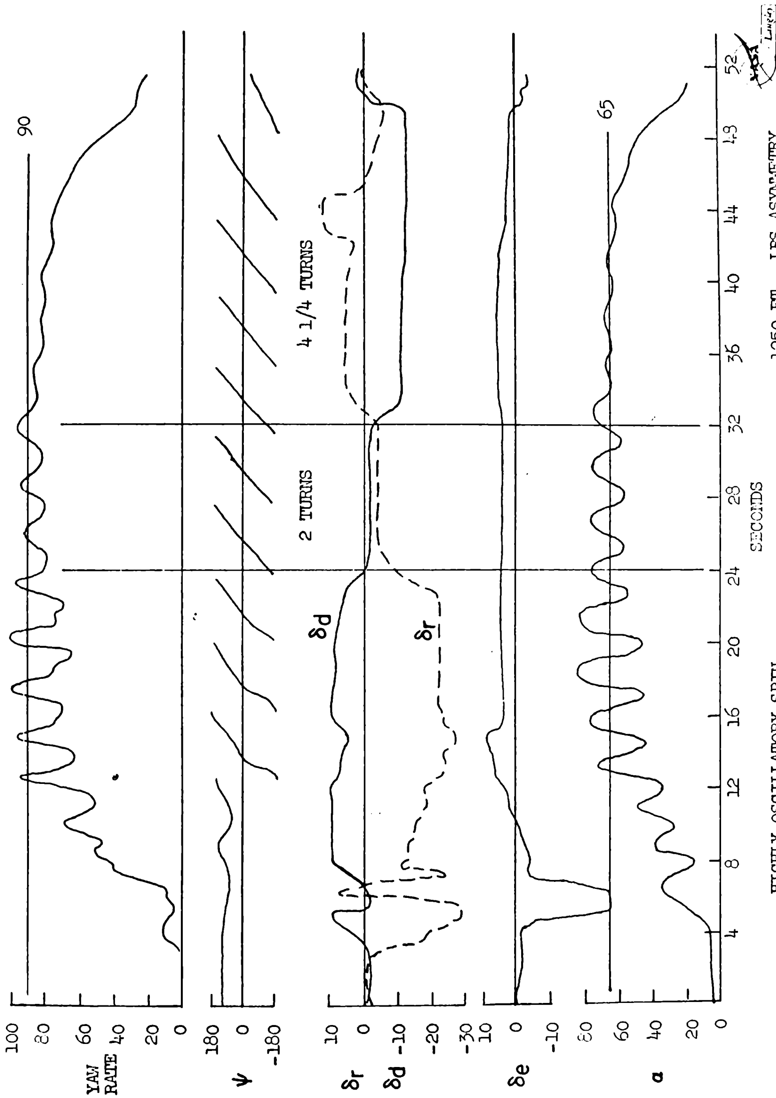
YAW RATE
ψ
δr
δd
δe
α
0
-50
-100
180
0
-180
20
10
0
-10
0
-10
60
40
20
0
-60
-75
60
δr
δd
13% SCALE
3/8 SCALE
SECONDS
10
20
30
40


YAW RATE
ψ
δr
δd
δe
α
SECONDS
0
-25
-50
-75
180
0
-180
20
10
0
-10
0
-10
-20
60
40
20
0
10
20
30
13% - SCALE
3/8 - SCALE


YAW RATE
ψ
δr
δd
δe
α
90
80
65
1 3/4 TURNS
3 1/2 TURNS
SECONDS
SMOOTH SPIN
1250 FT - LBS ASYMMETRY
NASA Langley

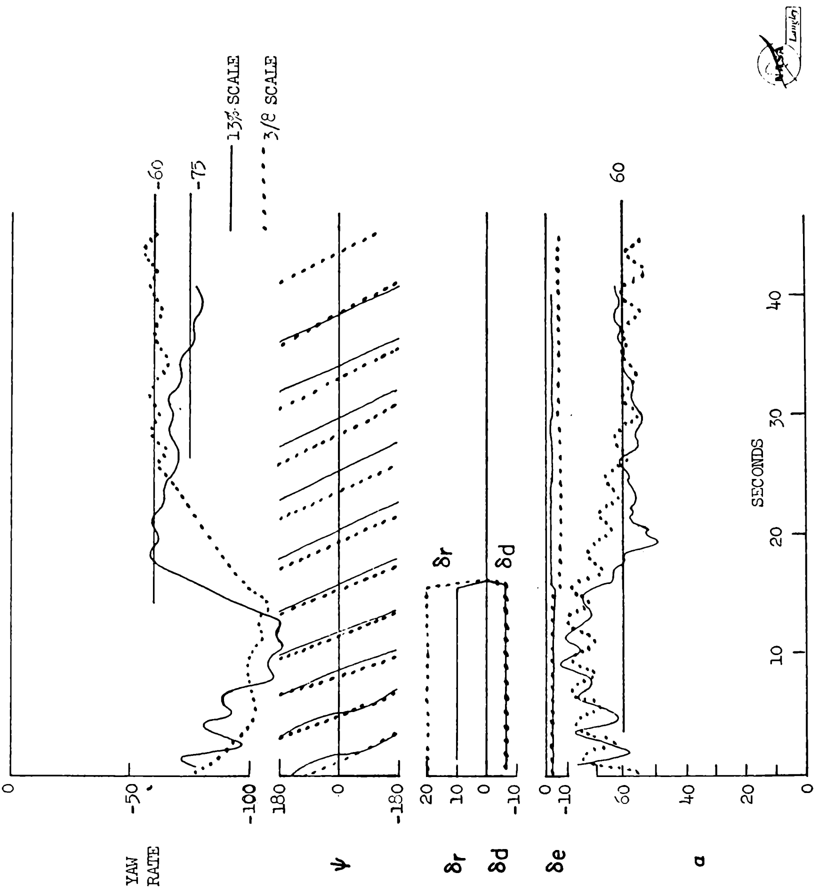


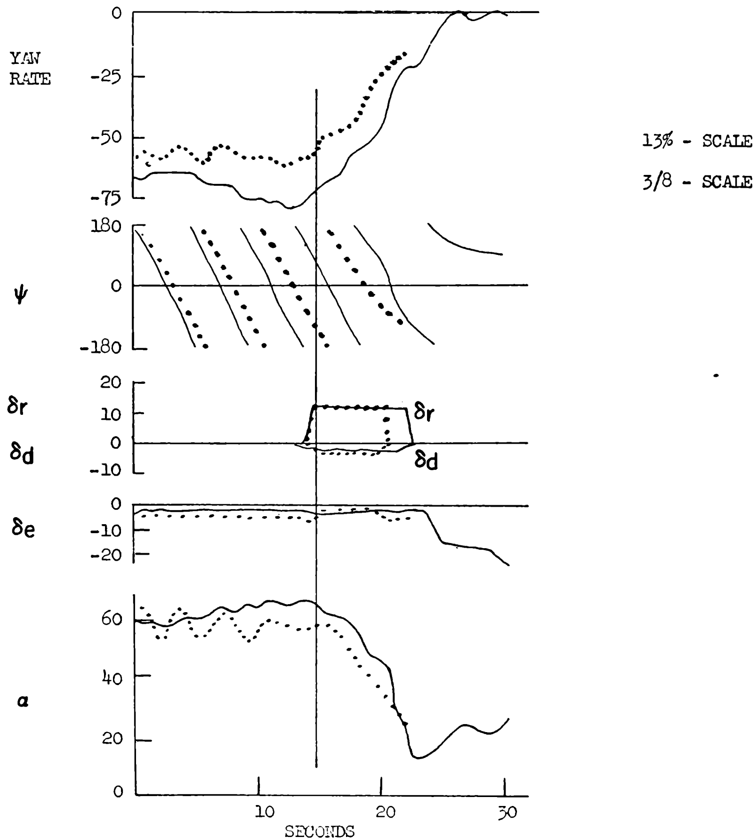
HIGH-α SPIN AND SMOOTH SPIN



HIGHLY OSCILLATORY SPIN

1250 FT - LES ASYMMETRY


YAW RATE
ψ
δr
δd
δe
α
SECONDS
13% SCALE
3/8 SCALE
-60
-75
60
0
-50
-100
180
0
-180
20
10
0
-10
0
-10
60
40
20
0
10
20
30
40
δr
δd


YAW RATE
-25
-50
-75
180
-180
ψ
20
10
0
-10
δr
δd
δe
-20
60
40
20
α
10
20
30
SECONDS
13% - SCALE
3/8 - SCALE

CORRELATION SUMMARY

AIRCRAFT CHARACTERISTICS	MODEL TEST RESULTS		
	SPIN TUNNEL	13% RADIO CONTROL MODEL	3/8-SCALE RPRV
Departure/spin resistant	---	X	X
Spin modes			
Oscillatory	X	X	X
Time/phase	---	X	X
Smooth	X	X	X
Recovery characteristics			
Oscillatory mode	X	X	NA
Smooth mode	X	X	X
Oscillatory damp/ slow-up recovery	X	X	X
Recovery controls	X	X	X

SUMMARY

- HIGH AOA HANDLING QUALITIES OBJECTIVELY DESIGNED INTO F-15
- DESIGN CONFIDENCE ASSURED BY COMPREHENSIVE AND TIMELY MODEL TESTING AND CORRELATION BEFORE INITIATION OF FLIGHT TESTING
- FLIGHT TEST PROGRAM CAREFULLY PLANNED
    - SAFETY
    - OPERATIONAL REQUIREMENTS
- FREQUENT/IN-DEPTH PROGRAM REVIEWS WITH MODIFICATIONS OF TEST PLAN AND EQUIPMENT AS REQUIRED

FLIGHT TEST RESULTS:

- VERIFIED WIND TUNNEL, MODEL, COMPUTER PREDICTIONS
- AIRPLANE ESSENTIALLY UNRESTRICTED
- ALL ANGLES OF ATTACK AND SIDESLIP (0-180°) ACHIEVED WITHOUT INCIDENT
- MOST OPERATIONALLY ACHIEVABLE OUT-OF-CONTROL MANEUVERS EXPLORED
- ENGINES PERFORMED BEYOND EXPECTATIONS
- SPIN CHUTE USED ONLY ONCE
- BACKUP HYDRAULIC SYSTEM NOT UTILIZED

RECOMMENDED AIRCRAFT MODIFICATIONS

- SPEEDBRAKE AUTO RETRACT
- 30°/SEC YAW RATE TONE-DEPARTURE TONE
- 60°/SEC YAW RATE/FULL LATERAL CONTROL AUTHORITY-SPIN RECOVERY AID
- SYMMETRIC WING FUEL TRANSFER
- ROLL CAS CUT-OFF AT 20.33° AOA
- ARI FAST TURN-ON
- POWER APPROACH SLOW SPEED WARNING

RECOMMENDED HANDBOOK RECOVERY PROCEDURE

- AIRPLANE OUT-OF-CONTROL (DEPARTURE TONE)-NEUTRALIZE CONTROLS
- IF NO RECOVERY (TONE PERSISTS) - RUDDER AGAINST ROTATION
- IF NO RECOVERY (TONE PERSISTS) - FULL LATERAL STICK WITH ROTATION
- AIRPLANE RECOVERED (TONE CEASES) - NEUTRALIZE CONTROLS