

# **MIT Lecture—Systems Engineering-Flight Control 1**

By Christopher Kraft ( NACA/NASA-1945 to 1982 )

## **Major Topics to be covered:**

### **Project Mercury**

Objectives of the program etc.

### **Development Of World-Wide Network**

#### Basic Requirements

Based on how often data required—set the location of number of stations ( Diplomatic issues) --use of available missile ranges—S and C band radar, telemetry, voice communications, ground communications, data retrieval and transmission, display.

### **Mission Plan**

#### **Evolution Of flight control concepts**

Concepts based on previous airplane flight test experience

Orbit Determination

Astronaut and systems health

Consumables analysis

Retrofire and landing point control

Contingency planning

Recovery planning-Very big operation involving all departments of the DOD

#### **Evolution Of Mission Control**

Centralized decision making really the determining factor—real time decisions

Data and information flow and display requirements

Computer complex—launch trajectory, orbit determination, retrofire and impact prediction

Communications requirements—air to ground—ground to ground

Recovery Control Center—Interplay with flight control

#### **Mission Rules Evolution**

a. Real time driven—need for careful thought pre event—time for unknown unknowns

b. Process had systems instrumentation and design effects

- c. Allowed top management review preflight
- d. Brought about support from design and development departments

### **Training—Simulation Systems Development**

Astronaut training requirements  
 Flight control training as well as network training and integration  
 Integrated astronaut and flight control training.  
 Initial rudimentary approach  
 Development of sophisticated approach

### **Dawn Of Systems Engineering**

- a. Definition of
- b. Development of the concept in flight control
  - 1. Systems diagrams
  - 2. Mission Rules and Malfunction Procedures.
  - 3. Brought about appreciation of interaction between systems and importance of knowledge of other systems.

### **Further Evolution of Flight Control Concepts**

### **Results Of Project Mercury And Lunar Challenge Brought Gemini And Apollo Programs.**

#### **Gemini Objectives Based On Apollo Mission Requirements:**

- A. Orbit Maneuvers- rendezvous and docking concepts and operational experience
- B. Long Duration Flight-up to 14 days because of lunar flight requirements
- C. Systems Development- Electrical Power, Caution and Warning, OMS-rocket development, Heat Protection-ablative materials
- D. Extra Vehicular Activities-Suit development-Back pack for EVA
- E. Entry Guidance- Maneuvering concept--On Board Computer-hardware-  
software requirements

#### **Advanced Mission Control Center**

- A. Computer and Communications Complex-Rendezvous, entry etc.
- B. Computer driven display system
- C. Advanced Simulation Requirements- Network simulation etc
- D. Remote sight modification-eventual satellite communication-data and voice, NASA satellite addition to network communications--full

time information.

E . Location-where to locate geographically--multi-mission (CSM and LM)- Agena target vehicle--rendezvous and docking.

## **Greatly Expanded Mission Rules And Malfunction Procedure Requirements**

### **Apollo Flight Control Requirements**

A. MCC design requirements-Besides Gemini and its requirements to operate one manned and one unmanned vehicle together-Apollo required support to two manned vehicles. Also the need to support two separate missions simultaneously --Gemini and unmanned Apollo tests--Two control rooms and associated communication and computer requirements.(Fortuitous flight control support to Gemini-76)

B. Computer analysis and support to entirely new set of orbital mechanics problems--Launch aborts, EO and TLI and possible earth return-free return trajectories and quick return to earth--LOI and its associated abort trajectories.

C. Lunar orbit determination--accuracy problems--Lunar gravitational anomalies found from Lunar Orbiter

D. Optimal lunar descent trajectories and abort from them--Landing point selection , accuracy and prediction--

1. Maximum performance vs. pilot view of landing site and choice of landing point.

E. Lunar launch trajectory and rendezvous requirements--rendezvous with CSM--LEM disposal and impact prediction--

F. EOI and attendant abort problems--

G. Translunar corrections to meet earth entry requirements, entry corridors and skip trajectory control

1. Landing point control and prediction including possibilities of weather avoidance.

H. Deep Space Network interfaces. Real time world wide communications--Tracking, telemetry, voice transmissions--phasing and use of numerous capabilities throughout US and the world--Spain and Australia.

I. Requirements of stated needs brought total revampment of MCC computer and communications complex.

## **Flight Control Support To Unmanned Apollo Development Tests**

A. Launch abort tests, TPS and CSM launch and reentry tests--use of Saturn V--Saturn V anomalies and program effects.

**All of above allowed for qualification of flight control concepts and flight controller training and qualification**

## **Apollo 1 Disaster**

A. Cause and effect

## **Formulation Of Apollo Test Program**

A. Unmanned development tests, manned tests to prove CSM and LEM hardware in EO, lunar operations pre landing attempt, lunar landing

B. Formulation of step by step test program, each phase building on the results of previous missions

1. Each category a set of objectives--number of flights required in each category thought possibly more than one depending on results.

## **Conception Of Manned Lunar Orbit Mission-Apollo 8**

A. LEM Problems--CSM ready as planned

B. Expedite flight objectives to reach moon

C. Lunar fly by vs. lunar orbit

D. Contingent on success of Apollo 7 EO flight and flight control readiness.

E. Probably Apollo's most significant flight

## **Apollo 11**

## **Apollo 13**

A. Flight control's finest hour.

## **Shuttle Challenges To Flight Control**

A. Use of aerodynamic capabilities--on board computer redundancy--systems redundancy

- B. Abort possibilities--use of aerodynamics and on board propulsion
  - a. Separation and recontact problems with ET
- C. TPS limitations-entry from launch abort and from orbit
- D. Weather avoidance for RTLS and normal entry
  - a. TPS damage--visual flight rules
- E. Flight control aides
  - a. Navigation and air data inputs
  - b. Intersection of HAC-energy control-glide slope-landing flare-gear deploy-GCA

### **Decision To Fly Manned Or Unmanned On First Flight**

- A. Risk analysis--design philosophy and systems reliability
- B. Low g flight made pilot less liable to health problems
- C. Training and simulation capability--fixed base, movable base, G-2 simulator--all added confidence for pilot capability.
- D. High risk factors--Launch abort-RTLS-entry aerodynamics and autopilot reliability-TPS-landing proficiency
- E. Pilot presence made system reliability significantly higher in all cases
- F. Discussed at highest levels of the agency--recommended by all management levels.
- G. Thoughts in retrospect--what unmanned capability would provide

### **Approach and Landing Tests**

- A. Orbiter transport--747 purchase and reconfiguration
- B. 747 offered landing test opportunity
- C. Need for proof of dead stick landing--pilot confidence and training
- D. Aid to development of landing techniques--flare and gear deploy
- E. Nay sayers doubted ability to "fly" orbiter off back of 747
- F. Test results--additional knowledge and experience always helpful
  - a. Control rates--airplane response to elevon control

### **Determining When To Fly First Shuttle**

- A. Admittedly difficult decision particularly because of manned first flight--first time a rocket system flown manned on first flight
- B. Critical design reviews--programmatic
- C. Design factors--structure at least FS-1.4 and quad redundancy in all orbiter critical systems--extensive engine tests to prove engine qualification--solid rocket tests and reliability (design flaw determined after flight tests)
- D. TPS concerns--structural integrity--SIP--Bond to aluminum skin, method of attachment, proof testing, TPS test articles--combined loads, lost tile concerns, critical tile criteria (surface density discovery), transition point, steps and gaps-established criteria, interference problems at doors and

aero controls and aero leak problems, instrumentation for post flight analysis

E. Entry control--aerodynamic properties, instability (gain changing), Monte Carlo analysis, landing point control, energy preservation and concepts (Use of G-2 provided pilot and program confidence)

F. Outside Expert Reviews--pros and cons

G. Final dissenters--thought TPS tiles would fail in the SIP or at the bond line due to vibration and or aerodynamic loads--NASA engineers disagreed on basis of tests and analysis

H. How decide when ready to fly? Simply--did not know what else to do so it was time to suck it up and GO.

I. Unknowns and “unknown” unknowns

**Opinion--Today's Travesty--Not Using STS and ISS.**