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Page 1 of 7
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SUBJECT

FLIGHT PROFILE CONSIDERATIONS FOR SOFIA

PROJECT SOFIA

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FLIGHT PROFILE CONSIDERATIONS FOR SOFIA

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9/18/86

Flight altitude, duration, and frequency considerations are given for SOFIA. This discussion is a preliminary attempt to integrate the major scientific, facility, and personnel constraints on the operation of the observatory. We would like to determine, within these constraints, what is the duration of routine observing flights and what is the number of flights per year which will produce the most science over the lifetime of the observatory. Additional goals are to make the operation as efficient and cost effective as possible.

Altitude

A minimum altitude requirement is that the observatory operate routinely above the clouds. The frequency of cloud interference during KAO operation at northerly latitudes drops to roughly tolerable levels as the observatory reaches about 40,000 feet, and becomes a rare occurrence at 45,000 feet. Beyond the need to be above the clouds, the scientific altitude requirements depend strongly on wavelength and spectral resolving power. Generally the far infrared and submillimeter observations benefit most from the highest altitudes, with near infrared and visible observations being less critical. Water vapor is the atmospheric constituent which varies most rapidly with altitude and is also the principal absorber of infrared radiation. KAO experience indicates that the precipitable amount of water in the line-of-sight frequently drops a factor of two in going from 41,000 to 45,000 feet; this may increase the photometric transmission at 100 μm by ~30%, or permit measurement of a spectral line in the wing of a terrestrial water line which would be impossible at the lower altitude.

A few KAO investigators prefer to stay at 41,000 feet because going higher would require comparing data taken at different altitudes, and therefore probably different amounts atmospheric water vapor, which can increase the errors in the data analysis. These investigators may want to use the same strategy on SOFIA, but would probably select a higher altitude if available.

Many KAO investigators do not request altitudes above 41,000 feet because of the inconvenience involved: for operation above 41,000 feet all personnel must have received high altitude physiology training, some members of the flight and telescope crew must breath oxygen continuously, and all others on board are restricted to their seats within arm's reach of their oxygen masks. Thus for the KAO, 41,000 feet is a threshold of sorts imposed by human physiology and flight safety considerations. The oxygen protocol above 41,000 feet is established by NASA, based on the unusual character of the C-141 airframe modifications. If this requirement can be eliminated it would considerably reduce crew irritation and fatigue on the high altitude flights, and presumably result in more observations above 41,000 feet.

Duration

Given the above altitude considerations, how long should routine flights be? Scientifically, longer flights permit intercomparison of more objects with minimum systematic errors, which are typically larger for data taken on separate flights. Longer flights tend to be more efficient in terms of data acquired per manhour of effort involved in preparing a mission for takeoff. Long flights are sometimes dictated by unusual events such as occultations and eclipses. Frequent short flights are appropriate for comet observations when the comet is near perihelion, or in order to achieve the higher average altitude possible when the plane takes off with less fuel. For example, 3 short flights may be much more productive than 2 longer flights with the same total flight time. Flights are typically limited to the hours of darkness, which for operation from Ames is as short as ten hours in summer.

A major constraint on altitude/duration is the physical capability of the airplane, for which the attached figure shows estimated performance. Currently a 72,000 lb payload and 20 sq. ft. drag increment are assumed. Altitudes up to about 47,000 feet are physically possible. A 7 1/2 hour flight would typically permit observations to start above about 40,000 feet, a half an hour after takeoff. Step climbing in 1000 or 2000 foot increments is the preferred climbing strategy for reasons of stability and flight safety. Thus roughly two hours of observing would be available at each of 41,000, 43,000, and 45,000 feet.

The flight duration is affected by crew considerations as well. For up to 7 1/2 hour flights, a 3-man flight crew is required; longer flights (up to roughly 15 hours) require a 4-man flight crew. Similar requirements may be appropriate for the telescope crew.

Thus the scientific altitude requirements, the altitude capability of the airplane, and the efficient use of flight crew personnel suggest that a routine flight duration of 7 1/2 hours is reasonable.

Frequency

Scientifically it is often desirable to repeat observations on separate flights to compare results as a check on systematic errors. Technical difficulties with the observations tend to occur on the first flight after installation of a focal plane instrument, so multiple flight series with a given instrument tend to improve observing efficiency. If the total number of observing hours are fixed by availability of resources, these are arguments for not reducing the flight frequency drastically to accommodate much longer flights. In addition of course, more flights for the observatory means more science groups can be supported.

The airplane can be operated at the 300+ level of flights per year, and so does not restrict the flight frequency for SOFIA. Twelve weeks of down-time for maintnainence is typical for the KAO operation and may be appropriate for SOFIA as well. Three flights per week for routine observing

with typically no more than one instrument changeout per week is probably a reasonable program for SOFIA, given the time required to install and verify the operation of focal plane instruments, to examine data from previous flights, etc. This results in 120 astronomy missions per year, although some of this flight time would be needed for engineering.

Frequency guidelines for flight crews would permit a dedicated 3-man flight crew to fly 133 flights of 7 1/2 hours per year, at a rate of up to 4 flights per week and 13 flights per month. At least one more flight crew member would be required for flights longer than 7 1/2 hours and as a substitute in case of illness in the crew.

In conclusion, science output would probably increase in proportion to the number of flights up to 150-200 flights per year. However, operational and personnel considerations may restrict the practical maximum number of flights per year to about 120. Further analysis will be required to estimate the resource requirements for different levels of flight operations.

Flight Profiles

Considering the above factors, it is important to provide considerable flexibility in the flight program. Several possible observing flight profiles are as follows:

1. Direct ascent to ~41,000 feet in 30 minutes;
   observations at that level for 6-1/2 hours;
   descent in 20-30 minutes;
   flight duration 7-1/2 hours.

2. Same as 1, except maintaining maximum altitude (step-climbing) during observations as permitted by the aircraft.

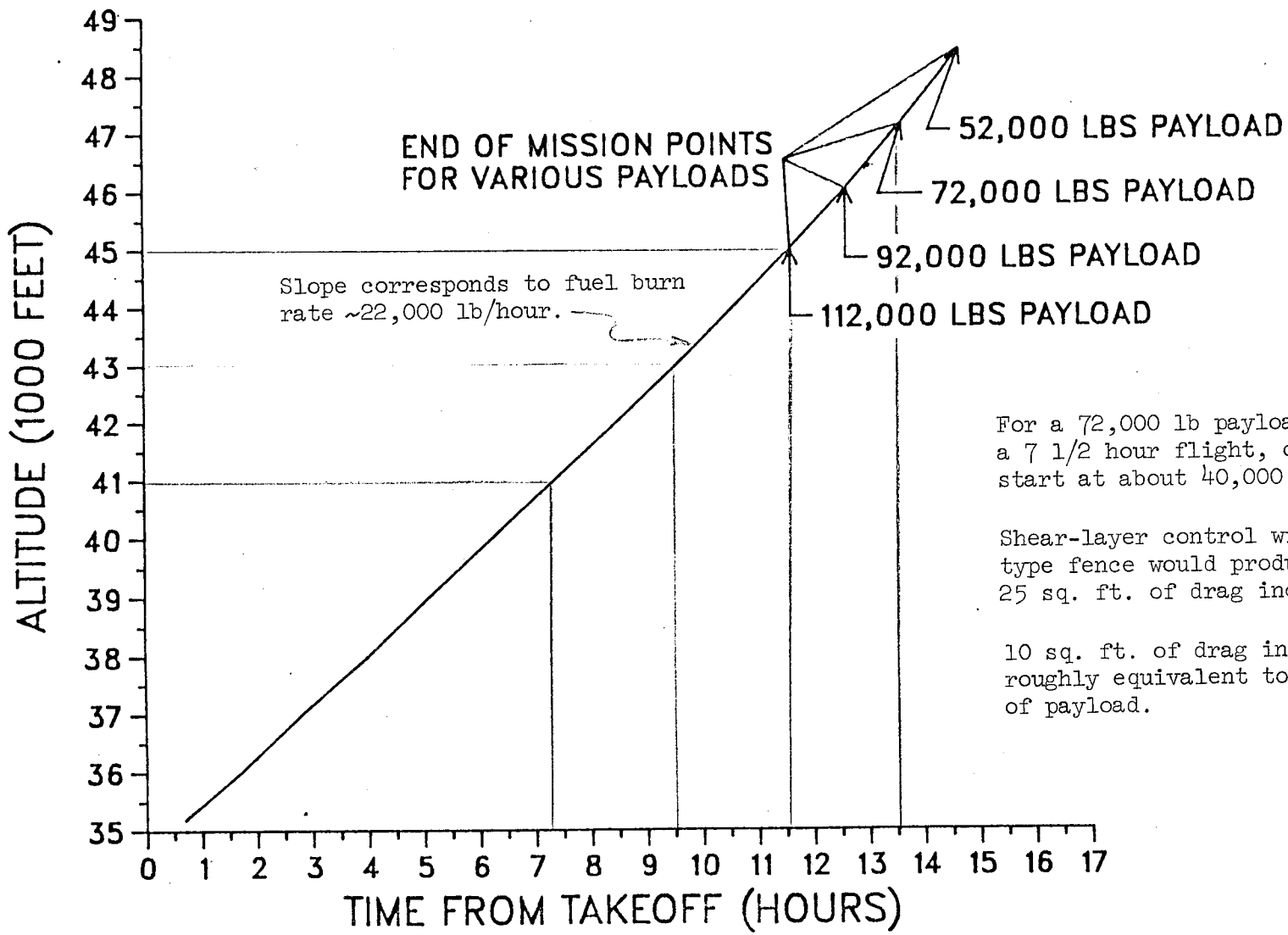
3. Ascent to 39,000 feet in 30 minutes;
   observations for 8 1/2 hours climbing to 41,000 feet when possible;
   descent in 20-30 minutes;
   flight duration 9 1/2 hours.

4. Same as 3, except maintaining maximum altitude.

5. Direct ascent to 43,000 feet in 30 minutes;
   observations at that level for 2 hours;
   observations at 45,000 feet for 2 hours;
   descent in 20-30 minutes;
   flight duration 5 hours.

747SP
(20 sq. ft. drag increment)

Note: the clean aircraft drag cross section is 165 sq. ft.



For a 72,000 lb payload and a 7 1/2 hour flight, observations start at about 40,000 feet.

Shear-layer control with a KAO type fence would produce about 25 sq. ft. of drag increment.

10 sq. ft. of drag increment is roughly equivalent to 20,000 lb of payload.